ESTIMATION OF THE PERFORMANCE OF SHELL AND TUBE HEAT EXCHANGER SYSTEMS WHEN UNCERTAINTIES EXIST

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PREFACE

A method for estimating the performance of shell and tube heat exchanger systems with uncertainties in the feed stream conditions and heat exchanger parameters has been developed. A computer program which will simulate heat exchanger systems of up to 100 elements has been written for this purpose and tested with a practical demonstration problem. The program makes it possible to determine the probable range of effluent stream temperatures and heat exchanger sizes.

I am gratefully indebted to my adviser, Dr. Kenneth J. Bell, for his help and guidance during the course of my doctoral program. I am also thankful to the members of my Advisory Committee for their always available assistance and constructive criticisms. The help provided by all faculty and staff of the School of Chemical Engineering is also acknowledged.

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NOMENCLATURE

A	- heat transfer surface area, ft^2
a	- effective heat transfer surface area per unit length, ft^2/ft
c	- heat capacity rate of the colder fluid, wc_p, BTU/hr^oF
C	- heat capacity rate of the hotter fluid, WC_p, BTU/hr^oF
c_p	- specific heat of the cold fluid, BTU/lb^oF
C_p	- specific heat of the hot fluid, BTU/lb^oF
D	- tube diameter, ft
E	- exchanger heat transfer effectiveness
E_f	- fin efficiency
E_T	- total effectivensss for more than one shell in series
f	- Fanning friction factor
$F_N(x)$	- cumulative normal distribution
$f_N(X)$	- probability density function
F_T	- configuration correction factor
g	- gravity acceleration, ft/sec^2
g_c	- conversion factor, lb_m-ft/lb_f-sec^2
H	- fluid enthalpy, BTU/lb
h	- film heat transfer coefficient, Btu/hr-ft^2-^oF
K	- thermal conductivity, Btu/hr-ft-^oF
ℓ	- fluid path length from 0 to any point in the exchanger, ft
L	- total fluid path length, ft

LMTD	- logarithmic mean temperature difference, ^oF
m	- number of shells
MTD	- mean temperature difference, ^oF
n	- number of tube-passes per shell
N	- the size of a sample
NTU	- number of heat transfer units
Nu	- Nusselt number
p	- probability or confidence level
Pr	- Prandtl number
Q	- total heat flow rate, BTU/hr
r	- tube radius, ft or inches
Re	- Reynolds number
R_f	- fouling film resistance, hr-ft^2-^oF/BTU
s	- sample standard deviation
sp	- specific gravity
T	- temperature of hotter fluid, ^oF
t	- temperature of colder fluid, ^oF
U	- overall heat transfer coefficient, BTU/hr-ft^2-^oF
V	- volume per unit length, ft^3/ft
v	- fluid velocity, ft/sec
W	- flow rate for the hotter fluid, lb/hr
w	- flow rate for the colder fluid, lb/hr
x	- random variable
$\overline{X}$	- the sample mean
Z	- standard normal deviate

Greek Letters

Δ	- increment for the accuracy of sample estimate
ΔP_r	- pressure drop due to abrupt change of direction, lb/ft^2
ΔP_t	- tube side pressure drop, lb/ft^2
ΔP_T	- total pressure drop, lb/ft^2
η	- viscosity of fluid, centipoise or $lb_m/ft\text{-}hr$
μ	- population mean for a variable
ρ	- fluid density, lb/ft^3
σ	-population standard deviation for a variable

Subscripts

A	- heat transfer surface area, ft^2
i	- inside of tube
o	- outside of tube
t	- tube
w	- tube wall conditions
1	- unless otherwise specified, integer 1 refers to conditions at the inlet of a heat exchanger
2	- unless otherwise specified, integer 2 refers to conditions at the outlet of a heat exchanger

CHAPTER I

INTRODUCTION

A major problem constantly faced by heat exchanger designers is to predict accurately the performance of an already designed single heat exchanger or a system of heat exchangers or modify the design so that it will perform the duty with a minimum cost. This is largely due to the existing uncertainties in the input variables and in the heat transfer characteristics and whether these uncertainties have been accurately accounted for in the design.

The ability of a designer to predict the performance depends upon the heat exchanger configuration, the heat transfer process, and the streams involved. His accuracy is also limited by the design methods chosen and the correlations employed. Even among nominally identical exchangers there are variations in dimensions due to manufacturing tolerances which lead to significant differences in performance. In addition, in any plant there are variations in feed stream compositions, conditions, and flow rate. Superimposed on all of these are daily and seasonal changes in air and cooling water temperatures.

Background

The method usually used by heat exchanger designers is to ignore in the original calculations all fluctuations in feed stream temperature, flow rates and heat exchanger dimensions and their effect on the heat transfer and fouling coefficients. Then, the exchanger is first designed according to the nominal values of the variables involved. After the area has been calculated, it is multiplied by a safety factor assigned by the designer to make sure the exchanger will perform adequately. The safety factor assignment is based mostly upon the designer's experience and judgment and can vary from 15 percent up to 100 percent with some designers to make sure that the equipment will be at least adequate (8). Such method can unnecessarily add to the cost of the equipment in capital investment.

Buckley (1950) was the first to use a statistical approach to the sizing of process equipment (8). For the sizing of a countercurrent heat exchanger, he suggested that first the size be calculated from the nominal values for temperatures, flow rates, heat capacities, and heat transfer coefficient. Then based on the assumption that uncertainties follow the normal probability curve, he determined the standard deviation for each assumed variable. From the individual uncertainties (standard deviations) the effect of each on the overall uncertainty of the area is determined and hence the overall uncertainty in the area σ_A is calculated. Once σ_A is known, the over-sizing can be determined according to the desired level of assurance or, as it is called, the confidence level. This method, although it gives a better idea of the safety factor needed, is not accurate in that it yields high safety factors and does not accurately represent the stochasticity of the process.

Another statistical approach to the determination of uncertainty in sizing process equipment has been suggested by Berryman and

Himmelblau (5) in 1973. Their method consists of the use of the Monte Carlo simulation of the process equipment where random but real fluctuations in the input variables and parameters are introduced in each simulation. Knowing the uncertainty in each variable and parameter involved, a random number generated from a normal distribution having the same mean and standard deviation of the variable considered to be fluctuating is substituted for the variable and the stochastic model for the process is solved. By having as many simulations of the process equipment as desired, the overall uncertainty in the size can be determined from the calculated standard deviation of the output sample and the level of confidence required.

The Monte Carlo Method has been commonly used in risk analysis of chemical plants to estimate profitability. The factors contributing to profitability are usually assumed to be normal even if it is known that they are not (17) because only normal and Poisson distributions can be easily manipulated mathematically.

For a steady state countercurrent heat exchanger Buckley used the integrated form of the design equation whereas Berryman and Himmelblau used the same equation in the differential form and integrated along the exchanger, which resulted in lower safety factors for the same exchanger. Although Berryman and Himmelblau's method reflects the stochastic behavior of the process better than Buckley's method, it requires both temperatures at one end of a countercurrent exchanger to be known to avoid trial and error procedure in each simulation. This is not always the case; often the inlet temperatures of the shell and tube sides are known and the outlet temperatures are to be calculated. The integration procedure for the temperature difference between the shell and tube becomes involved also when there is more than one tube pass per shell in the exchanger.

All this background indicates the degree of difficulty faced by heat exchanger designers in their quest for a design which could perform the duty assigned with a certain degree of confidence. If several heat exchangers are interconnected as in a crude preheat train, the task becomes greater and a method has to be found to both calculate the size of heat exchangers and estimate the probable performance of the exchanger system especially when the effluent streams are sensitive to small deviations above or below certain temperature limits.

In this study an attempt will be made to develop a computational procedure and a computer program which will simulate any system of shell and tube heat exchangers with a minimum of one exchanger and a maximum of 98 exchangers in a system. Each exchanger may have one to n tube passes per shell where n is an even number. The procedure will be somewhat similar to the one used by Berryman and Himmelblau in that it uses the Monte Carlo technique in generating and introducing normally distributed random numbers for all the input variables and exchanger parameters presumed to have uncertainties in them. The two methods then differ in the type of model equations used.

Depending on the job to be performed, the present method makes use of either the conventional exchanger design equation

$$Q = U_o A_o \mathrm{MTD} \qquad (1\text{-}1)$$

or the NTU-Effectiveness method. The first is utilized in the calculation of the heat exchanger surface area and the latter is utilized in the calculation of the outlet temperatures.

Whether the surface areas or the temperatures of the effluent streams from the system are calculated, the mean and standard deviation of each are also computed, upon where a confidence interval for each can be calculated corresponding to the specified confidence level.

From the results obtained certain questions can be answered such as:

1. For a specific confidence level, say 99 percent, what is the range of the effluent stream temperature for an existing exchanger?
2. Would an existing system of heat exchangers achieve the desired performance?
3. Which variable or parameter most affects the performance?
4. What is the surface area required in a heat exchanger if the designer is to be 95% confident that the outlet temperature is not lower than a certain temperature?

The answers to these questions and others can be found by performing the necessary statistical calculations. For question number 3, the answer is obtained by comparing the ratio of variances for the responses when all variables and coefficients are made to fluctuate and also when only one at a time is allowed to be randomly generated in each run.

CHAPTER II

LITERATURE REVIEW

Heat transfer equipment, in general, is made in several different geometric shapes and flow arrangements depending on the function required from the specific equipment in a process. Shell and tube heat exchangers are utilized in the recovery of sensible heat between two process streams. They are also employed in heaters and condensers where the latent heat of a condensing stream is recovered by another process stream. All types of heat exchangers, their functions, and methods of calculation have been covered in length in the heat transfer literature (1) (4) (20) (21) (22) (25). This work is concerned mostly with the effect of uncertainties in the process stream variables and shell and tube heat exchanger parameters on the effluent stream temperatures and heat exchanger areas. In this chapter a brief look at the main features of shell and tube heat exchangers, methods of calculation and the role of uncertainties in the prediction of their performance is presented.

Conventional Shell and Tube Heat Exchanger

Design Features

One of the most commonly used type of heat exchangers in the industry is the shell and tube heat exchanger. In this exchanger, heat is exchanged through the surface of a number of tubes laid out on either square or triangular patterns with one fluid flowing through the tubes and the other fluid outside the tubes. There are two tube sheets - one at each end of the tubes with matching holes into which the tubes are either rolled or welded to the tube sheet. The tubes are supported by crossbaffles on the outside; the baffles commonly used are called segmental baffles. These are drilled plates with heights equal to a fraction of the shell inside diameter (generally 75%). The baffles support the tube bundle and help to maintain the shell fluid in crossflow, which results in higher heat transfer coefficients. They are held together by baffle spacer rods screwed into the stationary tube sheet.

Figure 1 shows a one tube pass fixed tube sheet heat exchanger. The tube sheet is welded to the shell at both ends. This type can be built in almost any size (1).

Figure 2 shows a typical floating head heat exchanger with a removable tube bundle, giving one shell-side pass and two tube-side passes. There is a stationary tube sheet clamped between the shell flanges at one end of the tube bundle and a floating tube sheet which is clamped betwen the floating head flange and its backing device. By opening up the shell flanges, the tube bundle can be withdrawn from the channel end.

Figure 3 shows another type of shell and tube exchanger, the U-tube heat exchanger. It consists of tubes bent in a "hair-pin" shape and both ends of each tube are rolled into the tube sheet. Various arrangements for the types mentioned above exist in the literature. Some are more suitable than others for the kind of process under

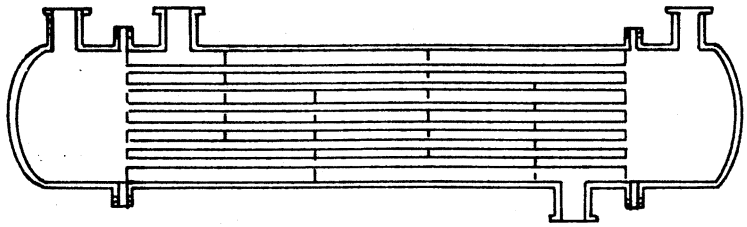


Figure 1. One Tube-Pass Fixed Tube Sheet Heat Exchanger

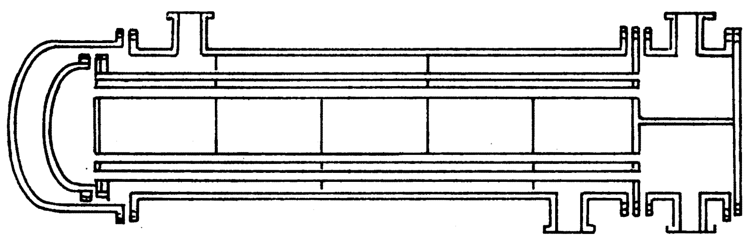


Figure 2. 1-2 Floating Head Heat Exchanger

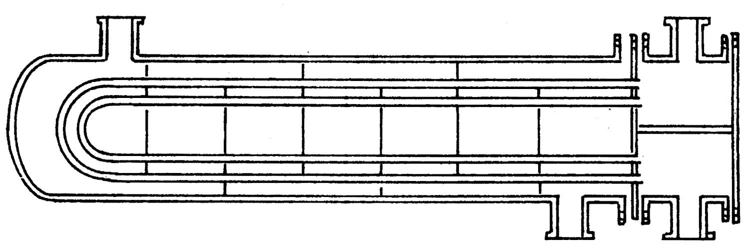


Figure 3. U-Tube Heat Exchanger

consideration in providing efficient heat transfer between the two streams. Some practical matters should be considered when choosing the mechanical arrangement such as preventing leakage from one stream to another, and ease of maintenance and servicing.

Materials of construction used in shell and tube exchangers are chosen on the basis of fluid being handled, process conditions and the total cost. The entire exchanger or some components of the exchanger can be constructed from a variety of metals such as carbon steel, stainless steel, copper, copper alloys, nickel, nickel alloys, aluminum and other special alloys. The conventional shell and tube exchangers can be produced in large quantities because of readily available standard materials and a well known manufacturing technique. For these reasons and the simplicity of the design, shell and tube heat exchangers are relatively inexpensive compared to most other possible heat exchanger configurations and lend themselves well to an enormous variety of services and process conditions.

Performance

Fluid on the shell side flows generally in cross flow outside the tubes. The number of parallel tubes per tube-pass is determined by the flow on the tube side (tube side velocity) and the number of tube-passes is determined by the heat transfer area required and the length specifications. The spacing for the cross baffles is established from the cross flow velocity on the shell side, which is in turn controlled by the pressure drop and vibration limitations.

Basic Fluid Flow and Pressure Drop Correlations in a Heat Exchanger

The shell side and tube side fluids are forced to flow through the exchanger passages by the pressure difference between the entrance and exit. This pressure difference is caused by either a pump or by hydrostatic head. The latter can be caused by changes in the density due to heating or cooling of the fluid, as in thermosiphon operation. Heat exchangers are designed to give pressure drops approaching the limits placed on the streams. Increased pressure drop allows increased velocities, which improve heat transfer.

If the tube fluid velocity is v, total length of the fluid path is L, tube inside diameter is D_i, the fluid density is ρ, and the viscosity is η, the pressure drop due to friction in lb/ft^2 is

$$\Delta P_t = \frac{2f\rho v^2 L}{D_i g_c} \left(\frac{\eta_w}{\eta}\right)^{0.14} \qquad (2\text{-}1)$$

where f is the Fanning friction factor read from a plot as a function of Reynolds Number ($Re = \frac{v\rho D}{\eta}$) for the fluid. The friction factor plot can be found in most fluid flow literature (23). The ratio of the fluid viscosity at the wall temperature and the viscosity at the bulk stream temperature is called the Sieder-Tate factor. Additional pressure drop in the tubes is due to the abrupt change of direction when there are more than one tube-pass.

$$\Delta P_r = \frac{4nv^2}{sp2g} \qquad (2\text{-}2)$$

where

sp = specific gravity

n = number of tube passes

v = velocity

g = gravity acceleration

The total pressure drop ΔP_T is the sum of the two pressure drops

$$\Delta P_T = \Delta P_t + \Delta P_r \quad . \tag{2-3}$$

For the shell side fluid pressure drop, the calculation is more complex than for the tube side. It basically involves the assumption of pure crossflow in tube bundles and the correction of the ideal pressure drop for leakage and bypass. One such method is the Delaware Method by K. J. Bell (3) (4).

Heat Balance

In a shell and tube heat exchanger if there is no heat loss to the surroundings, the heat given off per unit time by the hot fluid is assumed to be all taken up by the cold fluid. If the stream flow rates, terminal temperatures and specific heats were defined as W, T_1, T_2, C_p for the hot fluid and w, t_1, t_2, c_p for the cold fluid respectively, the heat balance equation is

$$Q = WC_p(T_1-T_2) = wc_p(t_2-t_1) \quad . \tag{2-4}$$

This equation is valid as long as there are no physical or chemical processes occurring which require or liberate heat energy (such as boiling or condensing). Equation (2-4) can also be expressed in terms of enthalpy which will include any change of phase of a fluid

$$Q = W\ (H_1 - H_2) \tag{2-5}$$

where W is the mass flow rate and H_1, H_2 are the fluid enthalpies at inlet and outlet conditions respectively.

Theoretical Limitation of Terminal Temperature

Since in a heat exchanger the heat gained by one fluid is the heat lost by the other fluid as seen in the heat balance equation, the outlet temperature of the two fluids are bound to each other by Equation (2-4).

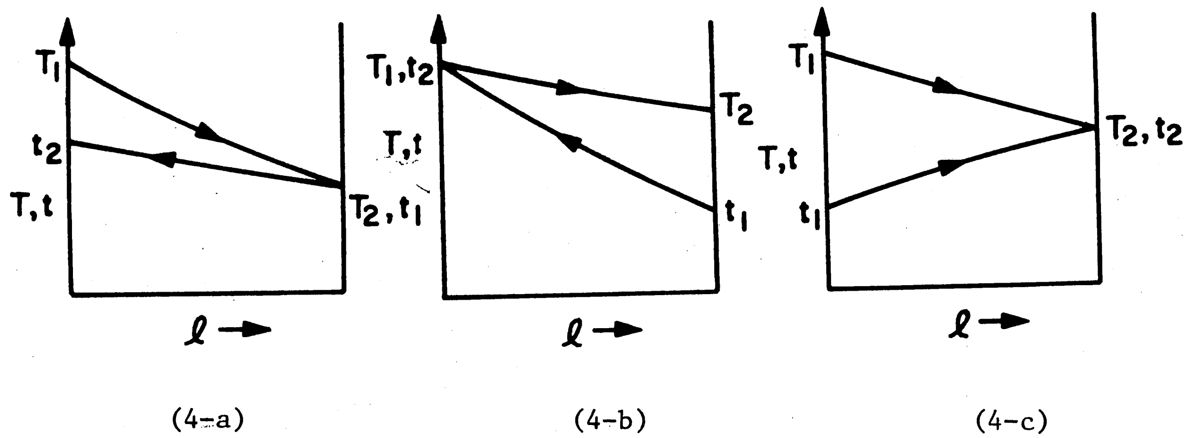


Figure 4. Terminal Temperature Limits for Countercurrent Flow (a,b) and Cocurrent Flow (c)

For the countercurrent flow, limiting temperatures can be calculated by setting the outlet temperature of the fluid of the largest temperature change equal to the inlet temperature of the other fluid as shown in Figures 4-a and 4-b above and solving for the outlet temperature from the heat balance equation:

$$\frac{t_2 - t_1}{T_1 - T_2} = \frac{WC_p}{wc_p} \quad . \qquad (2\text{-}6)$$

For cocurrent flow, the outlet temperature limit is found by setting the outlet temperature for both fluids T_2 and t_2 equal in Equation (2-6) as shown in Figure 4-c and solving for the temperature. In either case, in order for the exit temperatures to approach each other, an infinitely large heating surface is needed.

Analysis of the Shell and Tube Heat Exchanger Design Equation

The conventional design equation for heat exchange between two streams in a shell and tube heat exchanger is

$$Q = U\ A\ MTD \qquad (2\text{-}7)$$

where

Q = total heat flow rate

U = overall heat transfer coefficient

A = heat exchanger surface area

MTD = the mean temperature differences between the two streams

The overall heat transfer coefficient based on the outside area is evaluated from the total resistance to heat transfer between the two fluids

$$U_o = \frac{1}{\frac{1}{h_i}\frac{A_o}{A_i} + \frac{1}{h_o E_f} + R_{fi}\frac{A_o}{A_i} + \frac{R_{fo}}{E_f} + \frac{A_o \ln\left(\frac{r_o}{r_i}\right)}{2\pi L K_w}} \qquad (2\text{-}8)$$

where

h = film heat transfer coefficient

R_f = fouling film resistance

r = tube radius

E_f = fin efficiency

K_w = tube wall thermal conductivity

L = fluid path length

Subscripts o, and i, indicate the outside and inside heat transfer surfaces of the tube respectively. Fin efficiency E_f is introduced when the tube surface is finned, extended, or enhanced. For bare tubes E_f is equal to 1.0.

The overall heat transfer coefficient can be based on any surface area but the outside surface area is the most commonly used.

The Mean Temperature Difference

In a shell and tube heat exchanger, the two fluids undergo temperature changes along the tube length for both countercurrent and cocurrent flow arrangements which may not be considered linear (21). Figures 5 and 6 show the plot of the temperature profile for both counter and cocurrent flow.

At each point in Figures 5 and 6 the temperature difference (T-t) between the two fluids is different and a mean value should be arrived at. The derivation of the logarithmic mean temperature for concentic pipe heat exchangers can be easily seen when T-t is plotted against Q as has been discussed in Parker, et al. (25). The basis for the derivation is the set of assumptions stated in Kern (21) as follows:

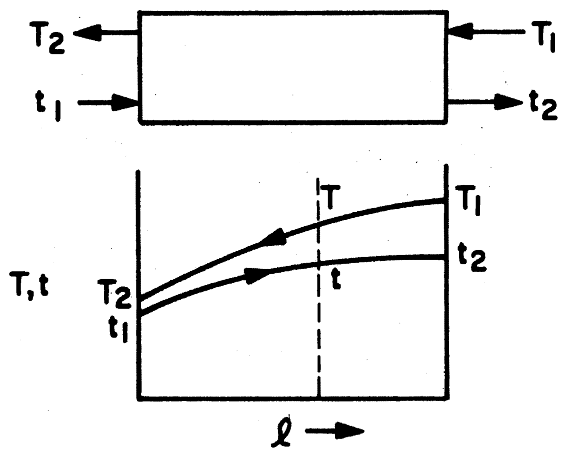


Figure 5. Countercurrent Flow

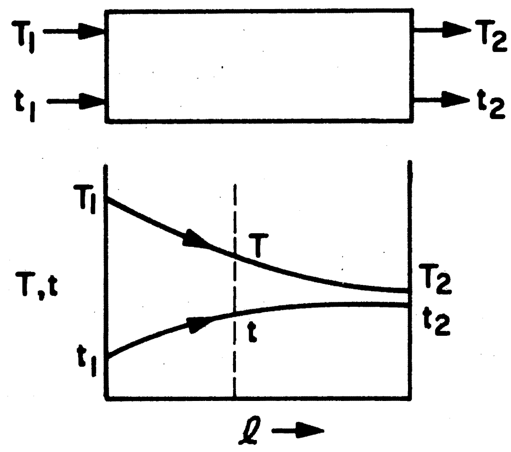


Figure 6. Cocurrent Flow

1. The overall heat transfer coefficient U is taken to be constant over the entire length.
2. The flow rate is constant.
3. The specific heat is constant for both fluids over the entire length.
4. There is no partial phase change in the system.
5. There is no heat lost or added to the system.

The steady state and the heat balance equations in the differential form for countercurrent flow are

$$dQ = U(T-t)dA \tag{2-9}$$

$$dQ = WC_p dT = wc_p dt \quad . \tag{2-10}$$

By integrating Equations (2-9) and (2-10) in the same direction and rearranging as shown in Kern (21) the result is that

$$MTD = LMTD = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln\left(\frac{T_1 - t_2}{T_2 - t_1}\right)} \tag{2-11}$$

where (T_1-t_2) and (T_2-t_1) are the differences in the two temperature at both ends of the path. For cocurrent flow the final equation is

$$MTD = LMTD = \frac{(T_1 - t_1) - (T_2 - t_2)}{\ln\left(\frac{T_1 - t_1}{T_2 - t_2}\right)} . \tag{2-12}$$

Configuration Correction Factor F_T

In a 1-2 heat exchanger the log mean temperature difference LMTD derived for pure countercurrent and cocurrent flow does not represent the true temperature difference in this case. The 1-2 heat exchanger is a combination of both parallel and counter flow as shown in Figure 7 and a new method is needed for the prediction of the true MTD. The method is based on the same assumptions mentioned in the derivation of LMTD for pure counter flow with the addition of two more assumptions (21).

1. The shell fluid temperature is an average isothermal temperature at any cross section.
2. The heating surface in one pass is equal to the heating surface in the other pass.

A detailed derivation of F_T for a 1-2 exchanger is in Kern (21) pages 140-144 and the final expression is

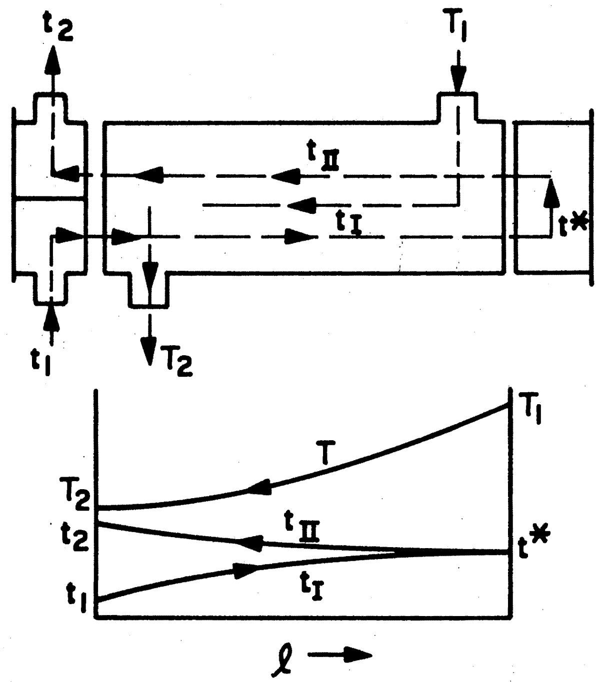


Figure 7. Flow Pattern and Possible Temperature Profiles for a 1-2 Heat Exchanger

$$F_T = \frac{MTD}{LMTD} = \frac{\sqrt{R^2+1}\ \ln\left(\frac{1-S}{1-RS}\right)}{(R-1)\ln\dfrac{2-S(R+1\sqrt{R^2+1})}{2-S(R+1+\sqrt{R^2+1})}} \qquad (2\text{-}13)$$

where

$$R = \frac{T_1-T_2}{t_2-t_1} \quad , \quad S = \frac{t_2-t_1}{T_1-t_1} \quad .$$

F_T is a correction factor which when multiplied by the LMTD for a true counter flow results in the mean temperature difference for a 1-2, 1-4, ... , 1-n shell and tube heat exchanger where n is even.

For heat exchangers with 2 shells in series and n tube-passes

Kern gives the following final expression for F_T

$$F_T = \frac{MTD}{LMTD} = \frac{\dfrac{\sqrt{R^2+1}}{2(R-1)} \ln \left(\dfrac{1-S}{1-RS}\right)}{\ln \dfrac{2/S-1-R+(2/S)\sqrt{(1-S)(1-RS)}+\sqrt{R^2+1}}{2/S-1-R+(2/S)\sqrt{(1-S)(1-RS)}-\sqrt{R^2+1}}} \cdot \quad (2\text{-}14)$$

Equations (2-13) and (2-14) are usually presented in the form of curves for different number of shell-passes and tube-passes in terms of R and S to make it easier for the heat exchanger designer. These curves can be found in the standard literature (21) (26).

NTU Method

Another method for calculating shell and tube heat exchanger performance is called the effectiveness-number of heat transfer units method or NTU-Method. This method relates the exchanger heat transfer effectiveness E as a function of the number of heat transfer units, the ratio of the smaller capacity rate to the larger one, and the flow arrangement. The terms are defined as follows

$$NTU = \frac{AU}{C_{min}} \quad (2\text{-}15)$$

$$E = \frac{Q}{Q_{max}} = \frac{C(T_1-T_2)}{C_{min}(T_1-t_1)} = \frac{c(t_2-t_1)}{C_{min}(T_1-t_1)} \quad (2\text{-}16)$$

where

$$C = WC_p$$

$$c = wc_p$$

and

$$E = f(NTU, \frac{C_{min}}{C_{max}}, \text{ flow arrangement})$$

where C_{min} and C_{max} are the smaller and larger heat capacity rate respectively.

The general expressions for the relations between the heat transfer effectiveness and NTU for different flow arrangements were derived by Kays and London (20). The final results are:

Cocurrent flow:

$$E = \frac{1 - \exp[-NTU(1 + \frac{C_{min}}{C_{max}}]}{1 + \frac{C_{min}}{C_{max}}} \quad . \qquad (2\text{-}17)$$

Countercurrent flow:

$$E = \frac{1 - \exp[-NTU(1 - \frac{C_{min}}{C_{max}}]}{1 - \frac{C_{min}}{C_{max}} \exp[-NTU(1-\frac{C_{min}}{C_{max}}]} \quad . \qquad (2\text{-}18)$$

Counter-Cocurrent flow (1-n exchanger, n is even)

$$E = \frac{2}{(1 + \frac{C_{min}}{C_{max}} + \sqrt{1 + (\frac{C_{min}}{C_{max}})^2} \; \frac{(1 + e^{-\Gamma})}{(1 - e^{-\Gamma})}} \qquad (2\text{-}19)$$

where

$$\Gamma = NTU\sqrt{1 + (\frac{C_{min}}{C_{max}})^2} \quad .$$

For heat exchangers with m shell passes and an overall countercurrent flow arrangement as shown in Figure 8, the total effectiveness E_T is expressed as (20)

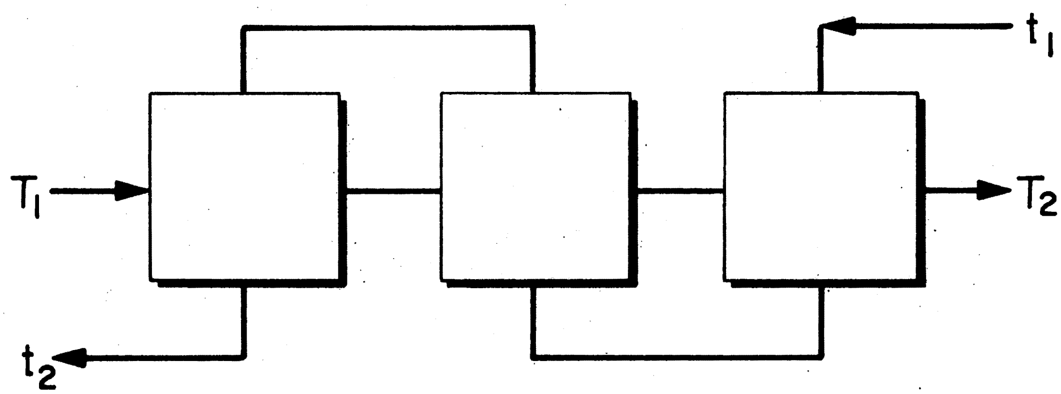


Figure 8. Three Shell-Pass Overall Countercurrent Flow Exchanger with Each Pass Having the Same Effectiveness

$$E_T = \frac{\left(\dfrac{1-E\dfrac{C_{min}}{C_{max}}}{1-E}\right)^m - 1}{\left(\dfrac{1-E\dfrac{C_{min}}{C_{max}}}{1-E}\right)^m - \dfrac{C_{min}}{C_{max}}} \qquad (2\text{-}20)$$

where E is the effectiveness calculated for each pass from Equations (2-17) to (2-19) and m is the number of identical shells.

Influence of Certain Variables on the Design of Heat Exchangers

Three different kinds of data are required to design a heat exchanger:

Process Data: Mass flow rates, terminal temperatures, and allowable pressure drops of both fluids.

Design Variables: Such as cross-sectional area, number of tube-passes, number of shells, etc.

Physical Properties: Density, specific heat, thermal conductivity, and viscosity of both fluids.

Heat transfer coefficients and pressure drops for the shells and tubes are usually evaluated from correlations of the process data and passage design. From these correlations a relationship between the variables can be established.

Depending on the conditions of the problem at hand, some parameters may be fixed such as the heat flow rate Q to be transferred or the heat exchanger size defined by the cross-sectional area, the length L and heating surface. It is desirable to know how significant is the effect of changing one of the other independent variables on the results expressed in one of the performance characteristics or heat exchanger dimensions.

The correlations for the heat transfer coefficients in both the tube side and shell side are expressed in terms of the dimensionless numbers Re, Pr, and Nu (4) (25). For the tube side when Re > 10,000 and L/D > 60, the heat transfer coefficient can be calculated from the following equation

$$Nu = 0.023\ Re^{0.8} Pr^{1/3} \left(\frac{\eta}{\eta_w}\right)^{0.14} \qquad (2\text{-}21)$$

when

Re = Reynolds number

Pr = Prandtl number = $\frac{C_p \eta}{K}$

Nu = Nusselt number = $\frac{hD}{K}$.

When the values for Re, Pr, and Nu are substituted into equation (2-21) we have the following relation for the tube side coefficient

$$h_i = 0.023\ v^{0.8} \cdot D^{-0.2} \cdot \rho^{0.8} \cdot C_p^{\ 1/3} \cdot K^{\ 2/3} \cdot \eta^{-1/3} \cdot \eta_w^{\ -0.14} \ . \qquad (2\text{-}22)$$

For the pressure drop equation (2-1) for the tube side, it can be expressed in the following form

$$\Delta p_t = 1 \cdot 44 \rho^{0.67} \cdot v^{1.67} \cdot D^{-1.33} \cdot \eta^{0.19} \cdot \eta_w^{\ 0.14} \cdot L^{1.0} \ . \qquad (2\text{-}23)$$

Equation (2-23) is based on the assumption that the tube side friction factor can be approximated by

$$f = 0.72\ Re^{-.33} \qquad (2\text{-}24)$$

Equations (2-21) to (2-23) show the impact of changing one variable while holding others constant for heat transfer coefficient h and pressure drop Δp in the tubes of a conventional heat exchanger. A change in the flow rate of one fluid or both for example will change the heat transfer coefficient in the tubes by an amount proportional to $v^{0.8}$. For ΔP, the change will be proportional to $v^{1.67}$ assuming all other variables are constant. In this case when only v, the velocity is allowed to change, h and Δp can be expressed in the form

$$h_i = C_1 v^{.8} \tag{2-25}$$

$$\Delta Pt = C_2 v^{1.67} \tag{2-26}$$

where C_1 and C_2 are constants. The same procedure can be applied to the shell side. Fluid velocity and diameter and length of a heat exchanger are dependent on each other and no one variable can be changed without affecting the others.

Pressure drop is usually limited by the effluent specified conditions and determines the velocity of both fluids, which in turn affects on the heat transfer coefficients.

Also, inlet temperatures limit the heat to be exchanged because the temperature difference between the two fluids is the driving force by which heat is transferred from the hot fluid to the cold fluid. Any fluctuation in one inlet temperature will require a change in the design heat transfer area if other variables, including the outlet temperature of the same fluid, are held constant.

Statistical Approach to Uncertainties

Fluctuation of the incoming flow rates due to sizing of tubes, maladjustment of valves and other process control equipment induced some fluctuations around the nominal values assumed for the flow rates of the heat exchanger's inlet fluid streams.

In addition to the flow rates, the temperatures of the inlet streams also fluctuate around their nominal values even in normal operation due to malfunctioning or maladjustment in the process controls up the streams, and due to fluctuating ambient temperatures. These fluctuations in the flow rates and inlet temperatures translate into variations in the local heat transfer coefficients as seen earlier in Equation (2-22). Inlet temperature changes will affect on the physical properties and the flow rate will affect both velocities. Such fluctuations result in a changing overall heat transfer coefficient, which will induce a change in the performance of a system of heat exchangers. In addition, there are always some uncertainties inherent in the ability to predict heat transfer coefficients from the given correlations and in our ability to estimate fouling resistances.

Since the incremental change in each of the variables mentioned above is mostly concentrated around the nominal value for each and there is little known about their distribution, it is usually assumed that each variable is normally distributed. This assumption is used because the normal distribution is the most amenable to simple mathematical manipulation.

The Monte Carlo Method

The Monte Carlo Method or as it is sometimes called, the method of statistical trials, is a system of techniques which makes it possible to simulate various types of random processes on a computer. The name Monte Carlo for a computation which employes random numbers was first applied by von Newmann and Ulam during the years of World War II when they used random numbers to simulate the behavior of neutrons. Several problems can be solved by the Monte Carlo Method. For each problem a random process is constructed where the parameters of the process equal to the required quantities of the problem. From observations of the random process and computation of its statistical characteristics, the quantities may be estimated which are approximately equal to the required parameters.

For example if μ is the mathematical expectation of a certain random variable, the Monte Carlo Method for determining the approximate value of μ is carried out by making N series of independent tests (N-sampling) of the value of the variable x: $x_1, x_2, \ldots, x_n$ and computing the mean value

$$\bar{x} = \frac{x_1 + x_2 + \ldots + x_N}{N}$$

where according to the law of large numbers

$$\bar{x} \approx \mu$$

$\bar{x}$ which has been determined by observations of the random process is approximately equal to the required quantity μ for a sufficiently large N.

The Monte Carlo method includes various degrees of simulation ranging from the simulation of actual physical systems to investigation of classical mathematical problems such as systems of linear algebraic equations. For further information concerning a specific technique refer to the literature in the field (14) (27).

The Normal Distribution

The most widely used continuous probability distribution is the normal distribution.

If X is a continuous random variable and the probability that X is less than or equal to x is (9)

$$P(X \leq x) = F_N(x) = \frac{1}{\sqrt{2\pi}\,\sigma} \int_{-\infty}^{x} e^{-(X-\mu)^2/2\sigma^2}\, dX \qquad (2\text{-}27)$$

X is said to be normally distributed and the constants μ and σ are the mean and standard deviation of X respectively. $F_N(x)$ is called the cumulative normal (Gaussian) distribution as shown in Figure 9. The derivative of $F_N(x)$ with respect to x is called the probability density function where

$$f_N(X) = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-(X-\mu)^2/2\sigma^2} \qquad (2\text{-}28)$$

The normal distribution curve, Figure 10, is completely determined by the mean μ and standard deviation σ where μ locates the center of the distribution and σ measures the dispersion of the individual measurements. All standard tables in the literature for normal distribution are for the distribution with μ=0 and σ=1 called the standard normal distribution. Equation (2-28) is rescaled to correspond to the standardized form by letting (29)

$$Z = \frac{X-\mu}{\sigma} \qquad (2\text{-}29)$$

and

$$f(Z) = \frac{1}{\sqrt{2\pi}} e^{-Z^2/2} \qquad (2\text{-}30)$$

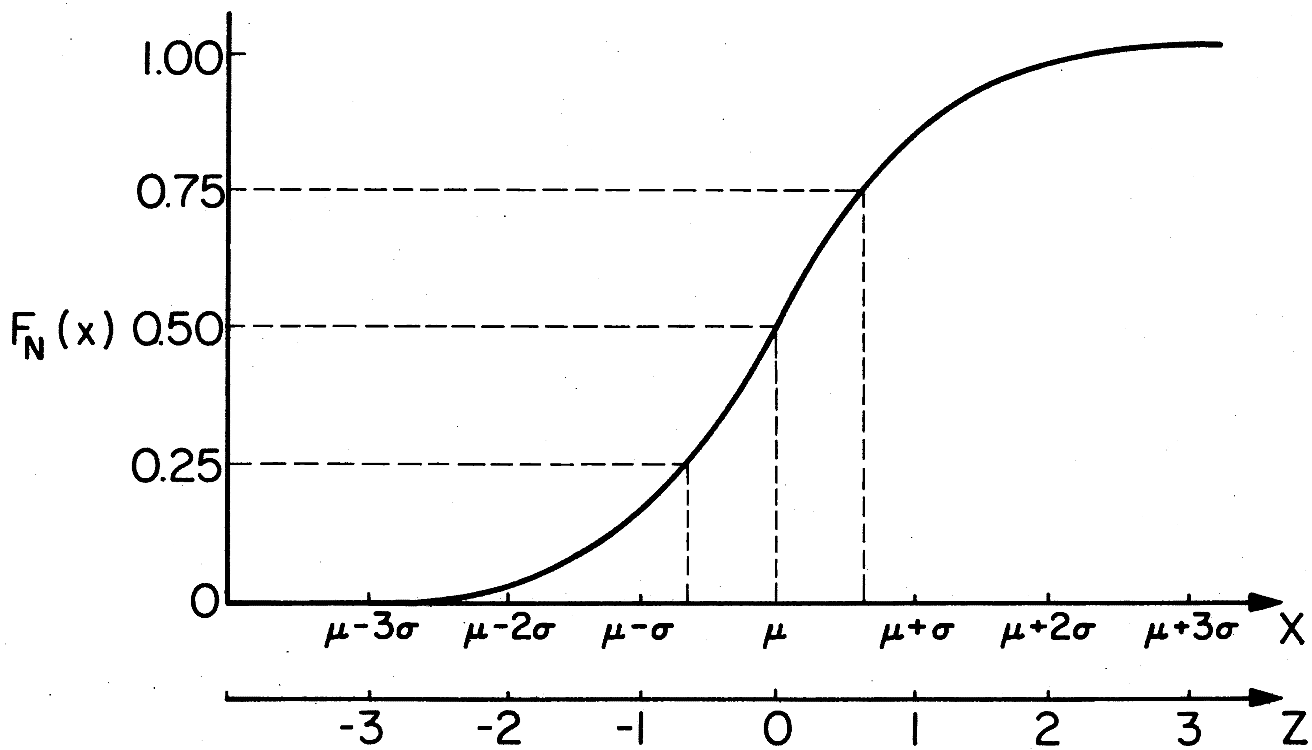


Figure 9. Normal Distribution Cumulative Function $F_N(x)$

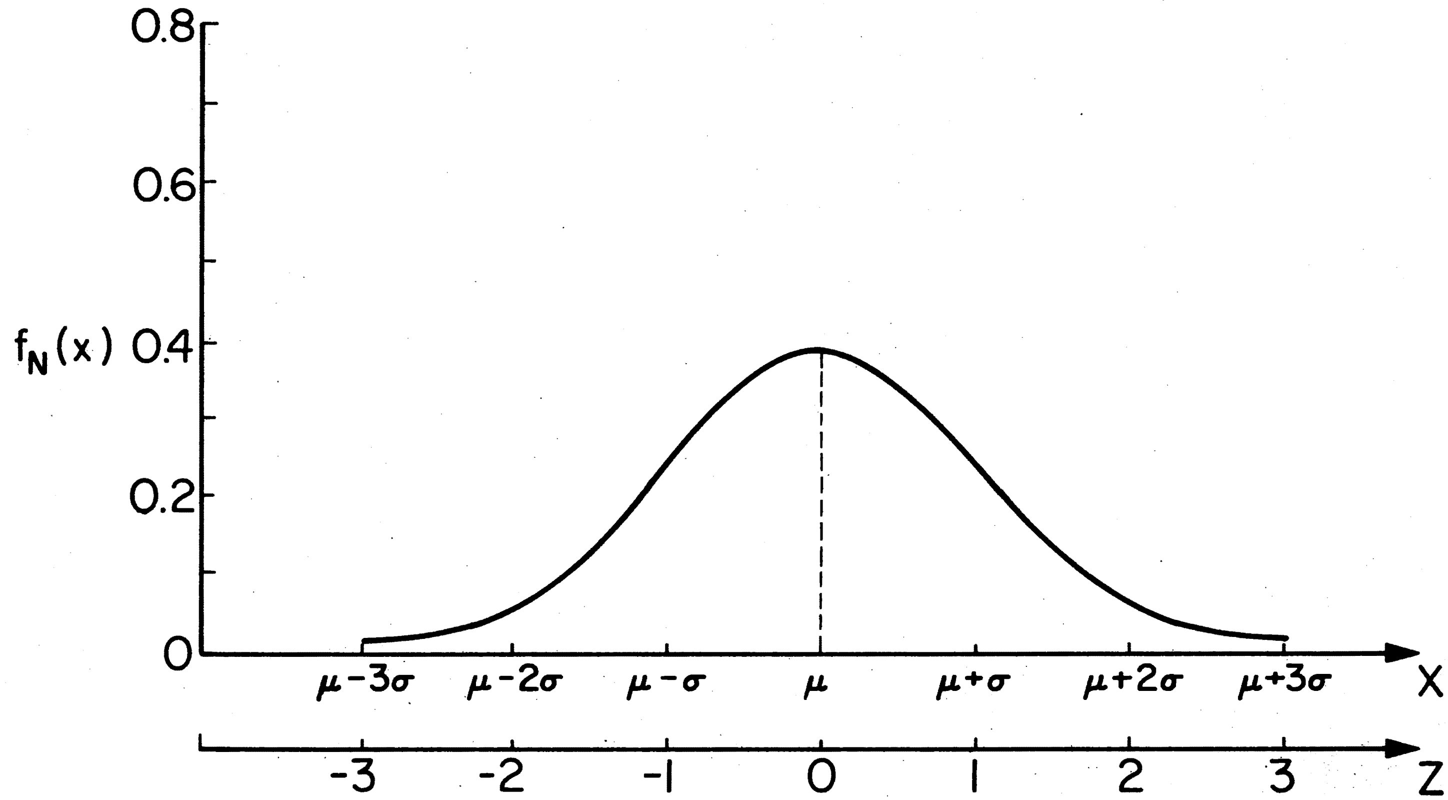


Figure 10. Normal Distribution Probability Density Function $f_N(x)$

where Z is called the standard normal deviate or the standard score. Although the population mean and standard deviation are seldom known, they can be estimated from random samples. If X is drawn from a normal population, $\overline{X}$ the sample mean is an estimate of μ and s, the sample standard deviation is an estimate of σ where

$$\overline{X} = \frac{\sum_{i=1}^{N} X_i}{N} \qquad (2-31)$$

and

$$s = \sqrt{\frac{\Sigma(X-\overline{X})^2}{N-1}} \quad . \qquad (2-32)$$

As shown in Figure 10 the normal curve is symmetrical about the mean; in the standard normal distribution, Z=0. The total area under the curve is 1.0 and the area (24) between Z=0 and Z=1.0 is equal to 0.3413; between Z=-1.0 and Z=1.0 is 0.6826. This is equivalent to saying that the probability of drawing a value from a standard normal distribution between $\mu \pm \sigma$ is .6826. It is then practically certain that any value drawn from a standard normal distribution will be between -3.9 and +3.9.

Confidence Interval

The confidence interval for a given population parameter indicates that in repeated sampling, N times, a known proportion (e.g. 99%) of the intervals computed by the same method will include the value of the parameter estimated. The percentage (99%) is called the confidence level and the interval ends are called the interval limits. If a variable X is drawn from a normal distribution, the probability is 0.95 that X lies in the interval μ-1.96σ to μ+1.96σ. This is called 95%

confidence interval for X. The population mean μ and standard deviation σ can be estimated by the sample mean $\bar{X}$ and standard deviation s if they are not known. The same procedure can be applied to calculate the confidence interval for the population mean μ. If a sample of N values was drawn from a normal population with a sample mean $\bar{X}$ and standard deviation s, the 95% confidence interval for the population mean μ is calculated as follows:

The standard normal deviate Z for a 95% confidence level is equal to 1.96 and the standard deviation of the mean is equal to $\sigma/\sqrt{N}$ where s can be substituted for σ when the latter is not known. The 95% confidence limits for the estimation of μ are given by

$$\bar{X} - 1.96\ s/\sqrt{N} \leq \mu \leq \bar{X} + 1.96\ s/\sqrt{N} \qquad (2\text{-}33)$$

In general, the confidence interval corresponding to any confidence level is

$$\bar{X} - Z\ \sigma/\sqrt{N} \leq \mu \leq \bar{X} + Z\ \sigma/\sqrt{N} \qquad (2\text{-}34)$$

when Z corresponding to the confidence level indicated can be read from the cumulative normal table provided in most statistics books (9) (29).

The one tail confidence limit is either the upper or lower limit for the parameter, but not both. Since the total area under the curve is equal to one and the curve is symmetrical about zero as discussed earlier, then for any confidence level p we find Z such that the area beyond Z in one tail is 1-p. For the upper limit of a 95% confidence level, the area from $-\infty$ to 0 is 0.5 and from 0 to Z is 0.45 and Z has the value of 1.645. This gives the upper limit for μ as $\bar{X} + 1.645\ \sigma/\sqrt{N}$.

Sample Size

Sometimes it is needed to know how large a sample one must take in order for the parameters to be meaningful. Such an answer is not readily available but an estimate can be made. If one sets a limit to the accuracy of one's sample estimate, say within $\pm\Delta$, then for the 95% confidence limit we know that $\overline{X}$ lies between $\mu \pm 1.96 \frac{\sigma}{\sqrt{N}}$ and

$$1.96 \frac{\sigma}{\sqrt{N}} = \Delta \tag{2-35}$$

or approximately

$$N = \frac{4\sigma^2}{\Delta^2} \tag{2-36}$$

and for 99% confidence level

$$N = 6.6 \frac{\sigma^2}{\Delta^2} \tag{2-37}$$

Use of Statistical Methods in Heat Exchanger Design

One of the earliest methods of applying the statistical approach to heat exchanger design is the one that had been suggested by Buckley (8) in 1950. The method is based on the mathematics of probability which provide quantitative evaluation of the uncertainties in the dependent variables which then permit a direct evaluation of the safety factors for a given level of assurance.

The procedure can be stated as follows: If Y is a function of several variables say $x_1, x_2 \ldots, x_n$ and σ_{x_i} (the standard deviation of x_i) is the uncertainty in the variable x_i, the uncertainty in Y due to the uncertainty in x_i is equal to $\frac{\partial Y}{\partial x_i} \sigma_{x_i}$. The overall uncertainty in Y is σ_Y and is expressed in terms of the individual uncertainties

$$\sigma_Y = \sqrt{\Sigma \left(\frac{\partial Y}{\partial X_i} \sigma_{x_i} \right)^2} \qquad (2\text{-}38)$$

Knowing the value of Y at the average conditions, an upper limit Y´ for Y is calculated based on the confidence level desired. The ratio of Y´ over Y is the safety factor needed.

An example cited by Buckley is a countercurrent heat exchanger which is to be designed to heat an organic fluid flowing at the rate of 25,000 lb/hr from a temperature of 100°F to 175°F. The specific heat for the cold fluid is 0.90 Btu/lb°F with a standard deviation of 0.05 Btu/lb°F. The hot fluid is another organic liquid with inlet temperature of 200°F and outlet temperature of 180°F. The specific heat of the hot fluid is precisely 0.86 Btu/lb°F. The overall heat transfer coefficient is assumed to have an average value of 55 Btu/(hr.ft.^{2}°F) and a standard deviation of 5 Btu/(hr.ft.^{2}°F).

The heat transfer surface needed is influenced by the two uncertainties in the cold fluid specific heat and the overall coefficient. Buckley calculated the average area and the influence of uncertainties on it using the design equation

$$Q = U\ A\ MTD \qquad (2\text{-}39)$$

where

$$Q = \text{heat duty} = wc_p(t_2 - t_1)$$

$$= 25{,}000 \times 0.9 \times (175-100) = 1.69 \times 10^6 \text{ Btu/hr}$$

$$MTD = LMTD = 47.5^\circ F$$

$$\text{Average Area, } A = \frac{1.69 \times 10^6}{55 \times 47.5} = 650.0 \text{ ft.}^2$$

The uncertainty in Q due to c_p is

$$c_p\sigma_Q = \frac{\partial Q}{\partial c_p}\sigma_{c_p} = w\Delta t\sigma_{c_p}$$

$$= 25{,}000 \times 75 \times .05 = 9.38 \times 10^4 \text{ Btu/hr.}$$

The uncertainty in A due to Q is

$$Q\sigma_A = \frac{\partial A}{\partial Q}\sigma_Q = \frac{1}{U\ MTD}\sigma_Q$$

$$= \frac{1}{55} \times \frac{1}{47.5} \times 9.38 \times 10^4 = 36.0 \text{ ft.}^2$$

The uncertainty in A due to U is

$$U\sigma_A = \frac{\partial A}{\partial U}\sigma_U = \frac{Q}{MTD} \times \left(\frac{-1}{U^2}\right)\sigma_U$$

$$= \frac{1.69\text{x}10^6}{47.5} \times \frac{-1}{55^2} \times 5 = -\ 59.0 \text{ ft.}^2$$

The overall uncertainty in A is

$$\sigma_A = \sqrt{(36.0)^2 + (-59.0)^2} = \pm\ 69 \text{ ft.}^2$$

For a 95% confidence level, the standard normal deviate Z is 1.645 and the total area needed is

$$A' = A + Z\ \sigma_A = 650 + 1.645 \times 69 = 764 \text{ ft.}^2$$

On a later date (1973) Berryman and Himmelblau (5) discussed the application of Monte Carlo simulation approach to study the effect of stochastic inputs and parameters on process analysis and design. For a heat exchanger the suggested method is the following: Assuming that all assumptions made for the derivation of the mean temperature difference are valid, the feed stream variables (temperature, flow rate, and specific heat) and the exchanger parameters (h_i, h_o, R_{fi}, R_{fo}) are to be generated randomly each from a distribution characteristic of the variable or parameter for each new simulation. The model equations are then integrated numerically along the exchanger in one direction. By repeating the simulations as often as needed, a sample of the required outputs is generated and the mean and standard deviation of the sample are calculated. From the resulting standard deviation of the specific outputs, statements can be made about the influence of uncertainties in inputs on outputs.

Berryman and Himmelblau compared their stochastic procedures with Buckley's method by working the same example of the countercurrent heat exchanger discussed above. Instead of solving the design equation for the area as Buckley did, they integrated the following differential equations

$$\frac{dt}{dA} = \frac{U\,(t-T)}{c_p w} \tag{2-40}$$

$$\frac{dT}{dA} = \frac{U\,(T-t)}{C_p W} \tag{2-41}$$

$$T = 180^{\circ}\mathrm{F} \quad , \quad A = 0.$$

The deterministic solution of Equations (2-40) and (2-41) for a cold fluid outlet temperature of 175.07°F using the same deterministic values mentioned earlier yielded an area of 650.0 ft.^{2} When the uncertainties in the cold fluid specific heat and the overall heat transfer coefficient were taken into effect by generating the value of each randomly from a normal distribution having the same mean and standard deviation as stated previously for each, the total area needed for the upper limit of a 95% confidence level was 715 ft.^{2}.

This results in a safety factor for the area of 1.10 compared to 1.175 calculated by Buckley. The difference was attributed by Berryman and Himmelblau to the use of the wrong stochastic model by Buckley.

The first method does not satisfy the first law of thermodynamics in the sense that the heat gained by the cold fluid was not equal to the heat lost by the hot fluid which in turn penalizes the outlet temperature of the hot fluid and mean temperature difference. It also is too conservative in that the designs are for the most extreme conditions which have a very low probability of occurring.

The second method uses the correct stochastic procedures but the integration processes become difficult for exchangers with more than one tube-pass. To integrate the difficult equations it is necessary to specify the value of outlet temperature of the hot fluid at the inlet of cold fluid. The calculated uncertainty in the inlet temperature of the hot fluid may not be equal to the actual uncertainty and this contributes an error in prediction of uncertainties in the output temperatures.

CHAPTER III

METHOD OF CALCULATION AND PROGRAM GENERAL DESCRIPTION

Method of Calculation

The main purpose of this research is to try to simulate the actual conditions for a given system of shell and tube heat exchangers in order to be able to estimate the performance of the system. The random fluctuations in input variables and heat exchange parameters will be reflected either in the outlet temperatures or the individual heat exchanger areas depending on which is to be calculated.

Model of Study

Although the study could be applied to any type of heat exchanger, the present study is restricted to a steady state shell and tube heat exchanger that is commonly represented by the integrated form of the design equation

$$Q = U_o A_o \, MTD \tag{3-1}$$

where

Q = total rate of heat transferred

U_o = overall heat transfer coefficient based on the outside area

A_o = outside surface area of heat exchanger

MTD = mean temperature difference between the two fluids.

Several assumptions have been made in order for Equation (3-1) to be applicable. These assumptions are (for each heat exchanger in the system):

1. Each stream flow rate is constant once it enters the heat exchanger.
2. Specific heat is constant for each fluid.
3. There are no partial phase changes in the heat exchanger. Evaporation or condensation does not exist in only a part of the exchanger or in only part of a fluid mixture.
4. The shell fluid is assumed to be completely mixed and its temperature constant across any cross-section.
5. The overall heat transfer coefficient is constant.
6. There are no heat losses to surroundings.
7. For heat exchangers with more than one tube-pass, area and flow are distributed uniformly among the passes.

For heat exchangers which are arranged in either cocurrent or countercurrent flow, the mean temperature difference between the two fluids is the logarithmic mean temperature difference, defined as

Countercurrent flow:

$$MTD = LMTD = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln \dfrac{T_1 - t_2}{T_2 - t_1}} \tag{3-2}$$

Cocurrent flow:

$$MTD = LMTD = \frac{(T_1 - t_1) - (T_2 - t_2)}{\ln \dfrac{T_1 - t_1}{T_2 - t_2}} \tag{3-3}$$

where t_1, t_2, T_1, and T_2 are the inlet and outlet temperatures of cold and hot fluid respectively.

For heat exchangers with two or more tube passes MTD is not equal to LMTD and a correction factor F_T is introduced in Equation (3-1) to correct LMTD for countercurrent flow, so that MTD = F_TLMTD and Equation (3-1) becomes

$$Q = U_o A_o F_T \text{LMTD} \qquad (3\text{-}4)$$

For heat exchangers with n tube-passes where n is even, the correction factors are

1-n heat exchangers (one shell-pass and n tube-passes):

$$F_T = \frac{\sqrt{R^2+1}\;\ln[(1-S)/(1-RS)]}{(R-1)\;\ln\left[\dfrac{2-S(R+1-\sqrt{R^2+1}}{2-S(R+1+\sqrt{R^2+1}}\right]} \qquad (3\text{-}5)$$

2-2n heat exchangers (two shell-passes and 2n tube-passes where n=2,4, 6,...):

$$F_T = \frac{\sqrt{R^2+1}\;\ln[(1-S)/(1-RS)]}{2(R-1)\;\ln\left[\dfrac{2/S-1-R+2/S\sqrt{(1-S)(1-RS)}+\sqrt{R^2+1}}{2/S-1-R+(2/S)\sqrt{(1-S)(1-RS)}-\sqrt{R^2+1}}\right]} . \qquad (3\text{-}6)$$

In the above equations,

$$R = \frac{T_1-T_2}{t_2-t_1} \quad , \quad \text{and} \quad S = \frac{t_2-t_1}{T_1-t_1}$$

The overall heat transfer coefficient U is computed from the local coefficients and fouling resistances

$$U_o = \frac{1}{\dfrac{1}{h_o} + \dfrac{1}{h_i}\dfrac{a_o}{a_i} + R_{f_i}\dfrac{a_o}{a_i} + R_{f_o} + \dfrac{a_o \ln (D_o/D_i)}{2\pi k_w}} \qquad (3\text{-}7)$$

h_i = tube inside heat transfer coefficient

h_o = shell side heat transfer coefficient

R_{fo} = shell side fouling resistance

R_{fi} = tube inside fouling resistance

D_o = tube outside diameter

D_i = tube inside diameter

a_o = tube effective outside area per unit length

a_i = tube effective inside area per unit length

K_w = tube wall thermal conductivity.

NTU Method

The use of Equation (3-4) requires the knowledge of all the terminal temperatures for both fluids. This may be a disadvantage because we are often interested in calculating outlet temperatures and a trial-and-error technique will be involved. The use of the number of transfer units (NTU) or as it sometimes is called - the heat exchanger effectiveness method - makes it possible to avoid any trial and error in determining the outlet temperatures when the surface area, configuration of heat exchanger, flow rates, specific heats, and heat exchanger coefficients are given.

Heat exchanger effectiveness is defined as the ratio of actual heat transferred to the maximum heat which could be transferred in a heat exchanger with an infinite surface area and purely countercurrent flow:

$$E = \frac{Q_{actual}}{Q_{max}} = \frac{WC_p(T_1-T_2)}{C_{min}(T_1-t_1)} = \frac{wc_p(t_2-t_1)}{C_{min}(T_1-t_1)} \tag{3-8}$$

where C_{min} is the smaller of the thermal capacities of the two streams.

The same assumptions made in arriving at Equation (3-4) can be applied to the NTU method. NTU is defined as

$$NTU = \frac{AU}{C_{min}} \quad ; \tag{3-9}$$

Also,

$$B = \frac{C_{min}}{C_{max}} \tag{3-10}$$

Kays and London (20) have shown that the heat exchanger effectiveness is a function of NTU, B and the flow arrangement, and can be expressed as

Countercurrent exchanger:

$$E = \frac{1-\exp[-NTU(1-B)]}{1-B\exp[-NTU(1-B)]} \tag{3-11}$$

Cocurrent exchanger:

$$E = \frac{1-\exp[-NTU(1+B)]}{1+B} \tag{3-12}$$

1-n exchangers (one shell and n tube-passes, n is even):

$$E = \frac{2}{(1+B) + \sqrt{1+B^2}\,[1+\exp(-\Gamma)]/[1-\exp(-\Gamma)]} \tag{3-13}$$

where

$$\Gamma = NTU\sqrt{1+B^2}$$

When there is more than one shell-pass in series with each pass having the same effectiveness E and the overall flow is countercurrent as shown earlier in Figure 8, the overall effectiveness is expressed in terms of the individual effectivenesses as in the following expression:

$$E_T = \frac{[(1-EB)/(1-E)]^m-1}{[(1-EB)/(1-E)]^m-B} \qquad (3\text{-}14)$$

In this case, m is the number of identical shell-passes, and E is the effectiveness of each shell. The individual shell-passes can be arranged in any one of the basic flow arrangements mentioned above as long as the fluids are mixed between passes and they are identical.

Application of Monte Carlo Technique

To simulate the effect of uncertainties in input variables and heat exchanger parameters involved in calculation of the performance of a system of heat exchangers, the Monte Carlo technique is utilized. The Monte Carlo method has been discussed in Chapter II and is simply a method of computation which uses random numbers and generates a large number of successive solutions for the system. The outputs from these solutions make up a sample where the ensemble mean and standard deviation for the system output can be computed.

The heat transfer coefficients and fouling resistances are usually assumed to be evaluated from experimental values by the least squares method (6) so each one can be estimated by a normal (Gaussian) distribution. These distributions are characterized by the given statistics of each parameter (such as the mean and standard deviation). A new normal random number is generated for each coefficient and fouling resistance in each simulation and each parameter is assumed to be constant during the simulation once it has been generated.

The uncertainties in the feed stream conditions (temperature, flow rate, and specific heat) are mostly distributed around their means (nominal values) and each can be approximated by a normal distribution of a given mean and standard deviation. For each simulation a different normal random number is generated for temperature, flow rate and specific heat if the nominal value and the standard deviation are specified.

In case the standard deviation for any of the variables cannot be evaluated from experimental data, an estimate of the standard deviation can be taken as one-eighth of the range of certainty (the difference between maximum and minimum values). For all practical purposes this estimate is justified, since it is more than 99.99% certain that a random number will be within $\pm 4\sigma$ from the specified mean value.

Flow rates are assumed to stay constant for the system for each simulation. This is to say that fluctuations due to maldistribution among exchangers in the system are neglected for a system of two heat exchangers or more. It is assumed that any maldistribution in flow rates will be compensated for in the heat transfer coefficients which will be generated randomly and independently of each other.

Description of Random Variables Used

Since it is assumed that uncertainties in variables and coefficients will mostly be comprised of small differences from the expected value for each rather than large differences, the normal distribution (when only the mean and variance are known), represents the maximum information known about the random variable in consideration. Two distributions are involved in the generation procedures of normal random deviates: the uniform and normal distributions. The methods are illustrated in the following:

1. Using an arbitrary seed, consisting of an odd integer with nine or less digits on the first entry, a nonrepetitive random integer is computed for the subsequent uses.
2. Using the random integers, uniform random deviates between 0.0 and 1.0 are generated with mean 0 and variance 1/12 (14) (19).
3. From the uniform random deviates, a normal random error (Y) with mean 0 and variance 1.0 is computed (19).
4. The normal random variable (Y) computed is then adjusted to the given mean and standard deviation $Y' = Y\sigma + \overline{X}$ where $\overline{X}$ is the deterministic value of the variable and σ is the variable standard deviation. The random numbers generated by this method have been extensively tested by chi-squared tests to verify that the random numbers were truly taken from normal distributions.

General Description of the Program

General Processing

A general purpose computer program has been written to simulate any system of shell and tube heat exchangers when there is no feed back. The program performs heat and mass balance calculations for any system configuration. Using selected process data, the program will calculate all process stream flow rates including some recycle streams without any special input by the user. It will also estimate the size (area) of each heat exchanger, calculate outlet temperatures, and calculate the statistics for all outputs as shown in the program flowchart (Figure 11).

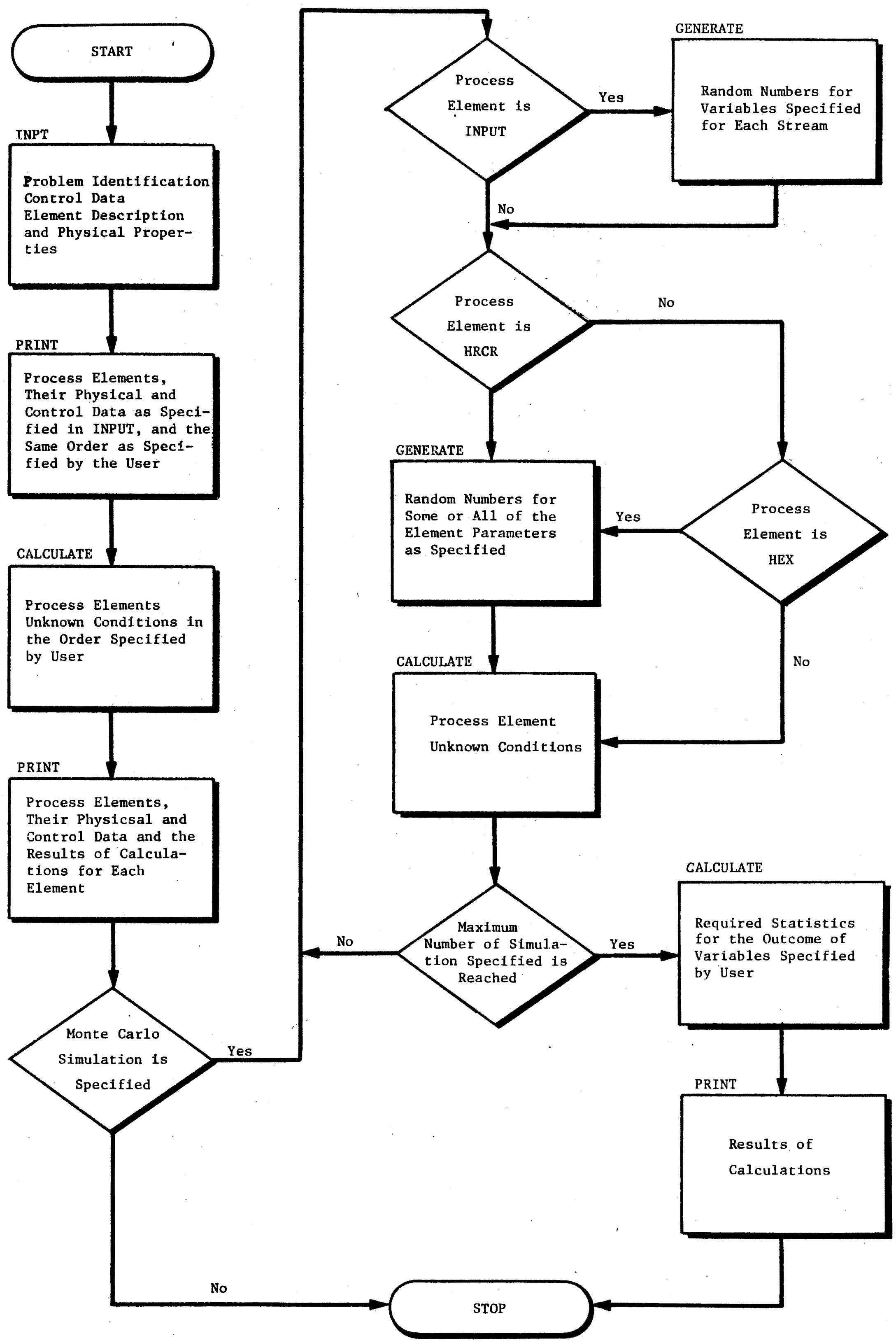


Figure 11. Computer Program Processing Flow Chart

Six different process elements can be simulated by the program. These elements are:

Input (INPT)
Output (OTPT)
Stream Adder (ADDR)
Stream Divider (DVDR)
Heater or Condenser (HRCR)
Heat Exchanger (HEX)

Inputs. The required inputs vary with the type of elements needed and the task to be performed. Depending on the job to be done, some or all of the following inputs are required.

1. flow rates, temperatures and specific heats for each feed stream
2. standard deviations for each of the flow rates, temperatures and specific heats
3. heat transfer coefficients and fouling resistances, and their standard deviations
4. heat exchanger sizes and flow arrangements

The user may want to input certain control data like:

1. whether the simulation is for only the deterministic model, or for both deterministic and stochastic models
2. number of iterations for the stochastic simulation
3. input and output units

Outputs. Outputs are printed in the same manner and will contain the following:

1. problem identification on each page of the output
2. the process element description in the same order specified by the user including calculation results for unknown variables

3. all input process data in the input system of units and the results of calculations in the output system of units specified

4. results of the Monte Carlo simulation for either outlet temperatures or areas

5. error comments to help the programmer to identify mistakes in input

A case problem is studied in Chapter IV and a complete computer output of the problem is included in Appendix A.

Description of Process Elements

Process Element Input-INPT. The Input element function is to serve as a feed tank for the whole system. All feed streams to the system must be included as product streams from the INPT element. The Input element has no feed streams and a maximum of 20 product streams. The temperatures, flow rates, and specific heats of the feed (product) streams are part of the input data.

Process Element Adder-ADDR. The Adder element function is to add a maximum of four feed streams into one product stream. The temperature and specific heat of the product stream are determined on the basis of a constant enthalpy process.

Process Element Divider-DVDR. This element function is to divide one feed stream into a maximum of four product streams. Only one feed stream and two to four product streams can be specified for this element. The fraction of the feed stream going into each product stream should be specified and the sum of all fractions must be equal to one.

Heater or Condenser Element-HRCR. In this element, a shell and tube heat exchanger is simulated in which a one-component fluid is condensed or boiled either in the shell or in the tubes. The temperature of the condensing or boiling fluid is assumed to be constant throughout the heat exchanger since only the latent heat is to be exchanged. The Heater or Condenser element has only one feed stream (the nonisothermal stream) and a corresponding product stream. The temperature of the isothermal fluid should be given to make the calculation possible.

Heat Exchanger Element-HEX. Process element Heat Exchanger simulates a shell and tube heat exchanger where only sensible heat is exchanged between the two fluids. It is assumed that there is no phase change in either fluid at any point in the exchanger. Two feed streams and two corresponding product streams must be specified for this element. If the feed and product streams are not specified in their designated places on the data card, execution of this element will not take place.

Process Element Output-OTPT. This element serves as a product tank to the whole system. All product streams from the system are included as feed streams to the output element. There are no product streams for this element and as many as 20 feed streams can be specified.

A summary of the process element is shown in Table I.

Preparing Input Data

To prepare the input data, specific instructions should be followed regarding the format for all input cards and the sequence of

TABLE I

PROCESS ELEMENTS IN PROGRAM

PROCESS ELEMENT TYPE	ELEMENT NAME	SUMMARY OF FUNCTION
Input	INPT	Serves as feed tank to the system.
Output	OTPT	Serves as product tank to the system.
Stream Adder	ADDR	Adds as many as two to four streams together and gives a single product. Constant enthalpy process.
Stream Divider	DVDR	Splits a single stream into two to four streams. All streams have identical composition, temperatures, pressures, and molar enthalpy.
Heater or Condenser	HRCR	Simulates either a heater or condenser (an exchanger with one isothermal stream).
Heat Exchanger	HEX	Simulates either cocurrent, countercurrent, or counter-cocurrent heat exchanger.

elements order. In order to avoid any problem failure due to mislocating an element in the system the following steps are suggested.

1. Draw a schematic flow diagram for the system.
2. Number all the elements in the system from 1 to 100 including the input and the output tanks. It is preferred that the numbering is in the same order that the calculation is to be carried out but it is not necessary.
3. Number the streams in and out of each element between 1 and 200 with no consideration given to the ordering of stream numbers.
4. Order elements (cards) in the order the calculations are to be carried out, paying attention to the continuation of flow of information from one element to the one next in line.
5. Input element should always be the first element in the sequence.
6. Output element should always be the last element in the sequence.

Card by Card Instruction

Problem Identification. This is the first card in the data set cards and 1 to 72 alphanumeric characters can be assigned. If none is assigned, no identification is printed but a blank card should be included instead.

Control Data Card. There are seven data spaces in this card. They are:

1. Number of Elements. An integer between 3 and 100 should be entered here. The number indicates how many elements are in the

system including input and output elements. The minimum integer is 3 since for only one heat exchanger the user will need input, heat exchanger, and output elements.

2. Monte Carlo Simulation. An integer value of 1 will cause the program to execute the Monte Carlo simulation. An integer of 0 will cause the program to perform only the deterministic simulation part. If no value is entered, the program will set the value to 0.
3. Number of Iterations. If Monte Carlo simulation is specified, then an integer in the range 1 to 500 should be entered here. If left blank, it is assumed that the Monte Carlo simulation is not specified.
4. The Seed Integer. An odd integer number with nine or less digits is needed to start the random numbers generation process. If only the deterministic simulation is specified, this space should be left blank.
5. Cumulative Probability Curves. An integer value of 1 should be entered in this space if the cumulative probability is to be calculated and a plot for each effluent stream temperature is to be included in the printout. If the Monte Carlo simulation is specified and this space is left blank, no probability curves will be printed.
6. Y-ordinate Scale. If the cumulative probability curves are specified, an integer number 1 to 60 (representing the number of intervals the total probability consists of) is entered here. The total probability is 1.0 and for an increment of 0.02, the number of intervals will be 50. If this data space

is left blank an integer number of 50 is assumed.

7. Temperature Increment. In order to calculate the cumulative probability for a certain temperature, the difference between the maximum and minimum value for the temperature is divided into intervals. The total number of intervals resulting is dependent on the temperature increment specified here. If cumulative probability curves are needed and this space is left blank, an increment of 1.0 degree is assumed for a total number of intervals 100 or less. If the temperature difference between maximum and minimum temperature is more than 100 degrees, an increment of 2.0 degrees is assumed. The temperature increment used will be evident in the X-ordinate for the plot.

Process Element Card. Each element must have a Process Element Card. In this card, an element is identified by certain features specific to the element. There are five data spaces in this card.

1. Element Number. An integer in the range of 1 to 100 should be assigned to each element and the specific number is entered here, right adjusted.
2. Number of Feed Streams to the Element. An integer in the range of 0 to 20 is entered here, right adjusted. The integer is dependent on the type of element under consideration as illustrated in Table II.
3. Number of Product Streams from the Element. An integer in the range of 0 to 20 is entered here as shown in Table II. If this space is left blank, a value of 0 is assumed.
4. Input Units for the Element. An integer of 1 or 2 is entered

TABLE II

SUMMARY OF THE ENTRIES TO PROCESS ELEMENTS

ELEMENTS	NUMBER OF FEEDS		NUMBER OF PRODUCTS		COMMENTS
	Min	Max	Min	Max	
INPT	0	0	1	20	No feed streams to INPT
OTPT	1	20	0	0	No product streams from OTPT
ADDR	1	4	1	1	
DVDR	1	1	1	4	
HRCR	1	1	1	1	
HEX	2	2	2	2	Each product stream must correspond to the feed stream on the same side.

here depending on the system of units the variables are given in. If the input variables are in the British system of units, enter integer 1, and if they are given in the International system of units, enter integer 2. If the space is left blank, a value of 1 is assumed.

5. Output Units for the Element. An integer of 1 or 2 is entered here depending on the desired output system of units. If there is no value assigned, a value of 1 is assumed.

Since the heat transfer coefficients are usually given either in Btu/hrft^{2o}F or W/m^{2}K, there are only two types of units allowed for in the program. These units are

Variable	British Units	SI Units
Heat Transfer Coefficient	Btu/hrft^2 F	W/m^{2}K
Thermal Conductivity	Btu/hrft F	W/mK
Specific Heat	Btu/lbF	J/kgK
Power	Btu/hr	W
Temperature	F	K
Length	ft	m
Mass	lb	kg

The program will convert from one system to another if one is specified as input and the other as output.

Process Element Input

Process Data Card. For each product stream of element Input, one process data card must be included in the data set. This card consists of seven data spaces:

1. Stream Number. An integer between 1 and 200 is assigned to each stream.
2. Flow Rate. The stream flow rate in the input units specified.
3. Temperature. The stream temperature in the specified units.
4. Specific Heat. The stream fluid specific heat. In the case where the fluid is a mixture of components and partial condensation is occurring inside the heat exchanger, an approximate procedure is used where a pseudo-specific heat for the mixture is calculated by dividing the enthalpy difference between inlet and outlet temperatures by the temperature difference.

$$C_p\,(\text{pseudo}) = \frac{H_{\text{at}_{T_1}} - H_{\text{at}_{T_2}}}{T_1 - T_2}$$

5. Flow Rate Standard Deviation. If Monte Carlo simulation is required and the stream flow rate is to be varied randomly, a value for the flow rate standard deviation in the same units as the flow rate must be specified. Otherwise this space is left blank.
6. Temperature Standard Deviation. If Monte Carlo simulation is required and the stream temperature is to be varied randomly, a value for the temperature standard deviation in the same units as the temperature must be specified. Otherwise this space is left blank.
7. Specific Heat Standard Deviation. If Monte Carlo simulation is required and the specific heat of the stream fluid is to be varied, a value for specific heat standard deviation in

the same units as those of the specific heat must be specified. Otherwise this space is left blank.

Process Element Adder

Process Data Card. This card consists of five data spaces. The first four spaces are designated for feed streams, and the fifth space is for the product stream. An integer number in the range 1 to 200 is entered for each feed stream and the product stream. For elements with less than four feed streams, a data space is left blank for each missing stream.

Process Element Divider

Process Data Card 1. This card consists of five data spaces for one feed stream and four product stream numbers. An integer in the range 1 to 200 is entered in each space. For elements with less than four product streams, a data space is left blank for each missing stream.

Process Data Card 2. This card consists of four data spaces, a space for each fraction of the feed stream going into the corresponding product stream. All fractions are positive numbers ranging in value from 0.0 to 1.0 and the sum should always be equal to 1.0. For each product stream missing, a corresponding data space is left blank.

Heater or Condenser Element

Process Data Card 1. There are four data spaces in this card. They are:

1. First Feed Stream Number. An integer number in the range 1 to

200 is entered here for the first feed stream, which is the nonisothermal of the two feed streams.

2. Second Feed Stream Number. This data space is assigned for the hotter stream where an integer in the range 1 to 200 is entered here. For the HRCR element only the nonisothermal stream is specified and this space should be left blank.

3. First Product Stream Number. This space is assigned for the first product stream number corresponding to the first feed stream. An integer in the range 1 to 200 should be entered here.

4. Second Product Stream Number. This space is assigned for the second product stream corresponding to the second feed stream. It is the hotter product stream which for the HRCR element should be left blank since only stream number is entered.

Process Data Card 2. This card consists of seven data spaces:

1. Heat Duty. The total heat flow rate in Watts or Btu/hr to be transferred can be specified or left to be calculated. If it is specified, it should be in the E-format.

2. Heat Exchanger Area. This is the total surface area of the heat exchanger. It should be specified if the temperature of the outlet cold stream is to be calculated and the heat duty is not given and cannot readily be calculated.

3. The Overall Heat Transfer Coefficient. If the overall heat transfer coefficient based on the outside area is known, it should be entered here - if not, it should be left blank.

4. The Tube Inside Coefficient. If the overall coefficient is

not known, a value should be entered here for the tube inside heat transfer coefficient.

5. The Shell Side coefficient. If the overall coefficient is not specified, the value of the shell side coefficient should be entered here. Otherwise this data space should be left blank.
6. Tube Inside Fouling Resistance. If the inside fouling resistance is known and the overall coefficient is not specified, the value of the tube inside resistance should be entered here. Otherwise this data space should be left blank.
7. Shell Side Fouling Resistance. If the shell side fouling resistance is known and the overall coefficient is not specified, the value of the shell side resistance is entered here. Otherwise this data space is left blank.

Process Data Card 3. This card consists of seven data spaces:

1. Tube Inside Effective Area. This data space is for the tube inside effective area per unit length of the tube.
2. Tube Outside Effective Area. The tube inside and outside effective area should be in the same units.
3. Isothermal Stream Temperature. This is the condensing stream and its temperature should be specified if the heat exchanger area is to be calculated.
4. Isothermal Stream Flow Rate. If the heat duty of the exchanger is not given and it is to be calculated from the flow rate and the latent heat of the condensing vapor, the flow rate is entered here. Otherwise this space is left blank.

5. The Fluid Latent Heat of Condensation. If latent heat of condensation is needed, it is entered here. Otherwise the data space is left blank.

6. First Product Stream Temperature. This is the outlet temperature of the colder stream. If the heat exchanger area is to be calculated and the heat duty is not specified, a value for the outlet temperature is entered here. Otherwise this space is left blank.

7. Second Product Stream Temperature. This is the outlet temperature of the hotter stream. For the HRCR element this data space is left blank.

Process Data Card 4. This card consists of seven data spaces:

1. Cold Stream Specific Heat. If a pseudo specific heat of the cold fluid, or an average value calculated for the inlet and outlet specific heats of the stream is needed, the designated value is entered here. A specific heat value entered in this space overrides the value designated for the stream fluid from a previous calculation on the basis of a constant specific heat assumption. If specific heat is constant, this space is left blank.

2. Hot Stream Specific Heat. For HRCR element, this data space is left blank.

3. Tube Inside Diameter. The tube inside diameter is entered here if the resistance due to the tube wall is to be calculated. If tube wall resistance is not to be considered, this space is left blank.

4. Tube Outside Diameter. The same rules applied to tube inside diameter also apply to the outside diameter.
5. Tube Wall Thermal Conductivity.
6. Flow Arrangement. For Heater or Cooler element only one type of arrangement is possible, namely countercurrent flow. In this case this data space is left blank.
7. Number of Shell Passes. The number of shell passes in series should be entered here. This number is an integer always greater than zero.

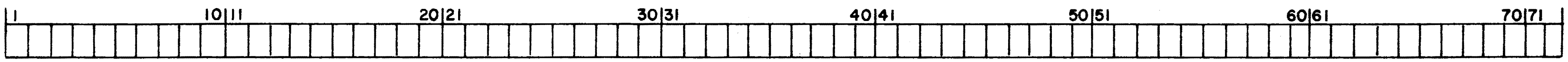
Process Data Card 5. There are seven data spaces in this card. These spaces are designated for the standard deviations of the parameters; overall, tube inside, and shell side coefficients, tube inside and shell side fouling resistances, cold and hot fluids specific heats respectively. If Monte Carlo simulation is specified, the standard deviation of the variable which is to be varied randomly is entered in the appropriate data space as shown in the input data forms (Figure 12).

Heat Exchanger Element

Process Data Card 1. There are four data spaces in this card:

1. First Feed Stream Number. The colder stream of the two feed streams is the first feed stream. An integer in the range 1 to 200 should be entered in this space.
2. Second Feed Stream Number. This stream is the hotter stream of the two feed streams and the integer assigned for this stream is entered here.
3. First Product Stream Number. This stream corresponds to the

PROBLEM IDENTIFICATION CARD



CONTROL DATA CARD

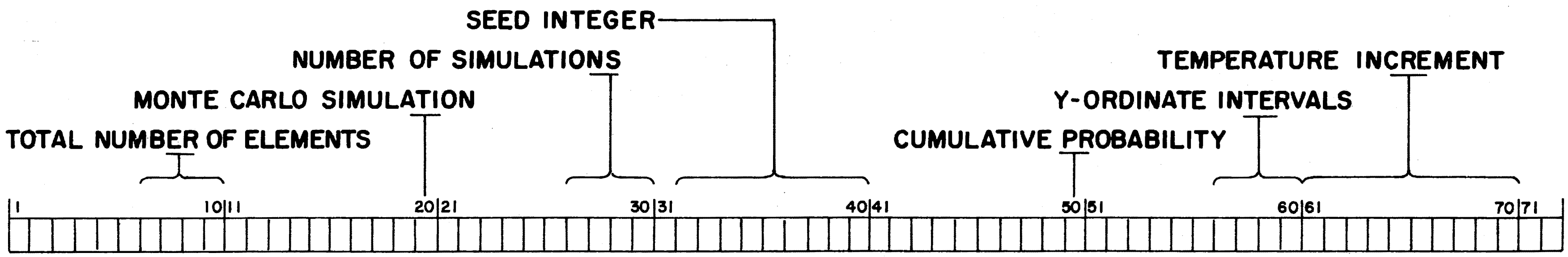


Figure 12. Input Data Forms

INPUT ELEMENT

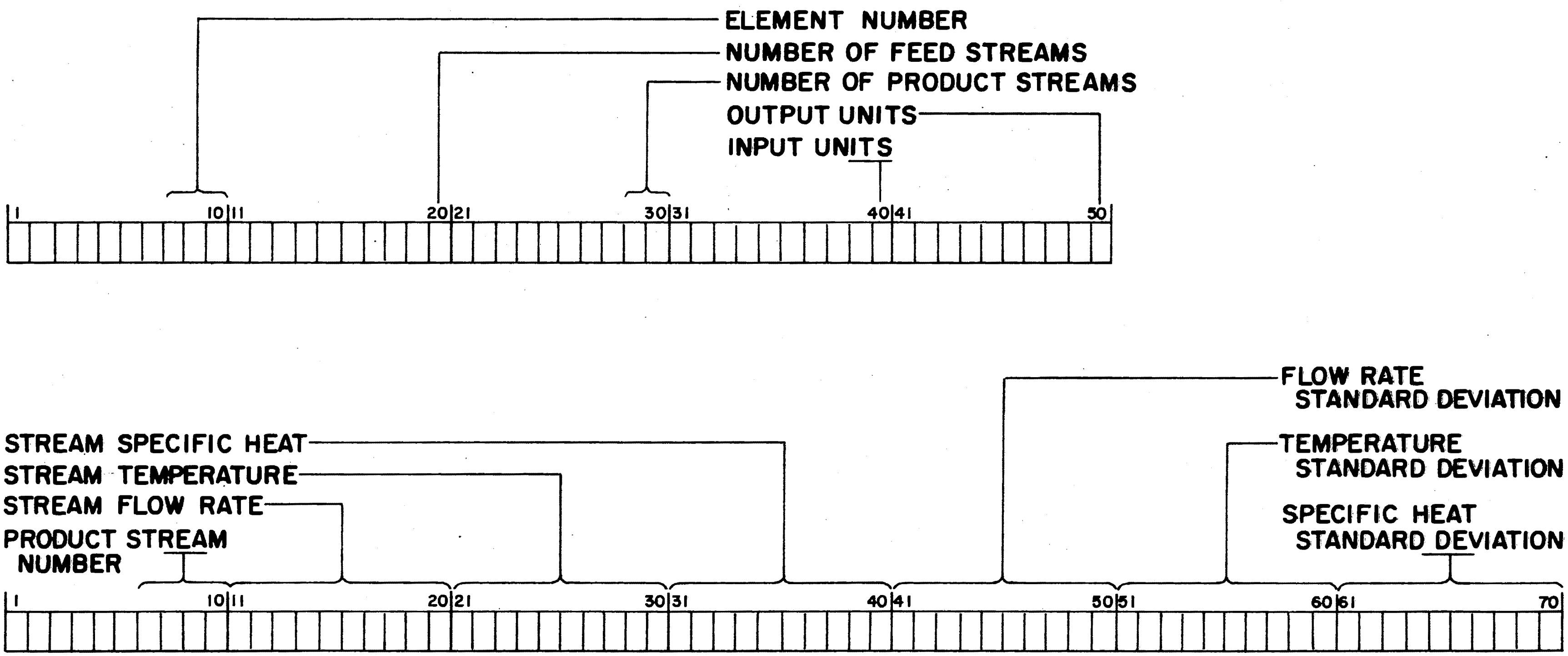
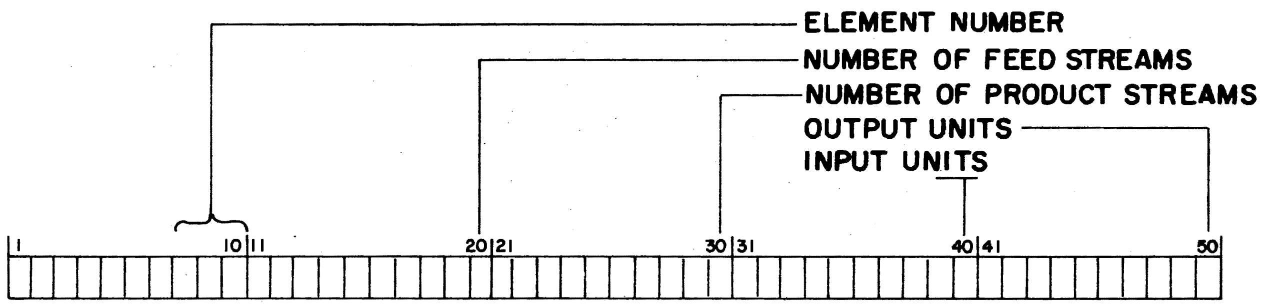


Figure 12. (Continued)

ADDER ELEMENT



FEED STREAM NUMBER 1 TO 4

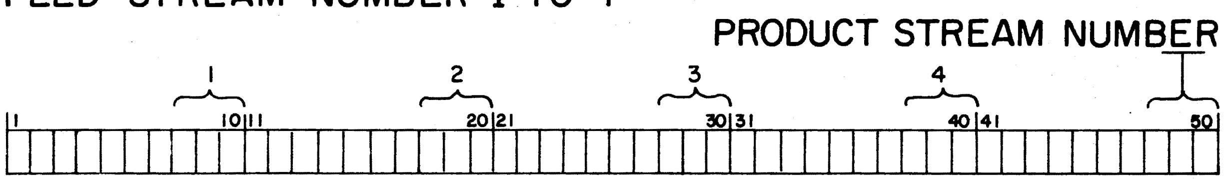


Figure 12. (Continued)

DIVIDER ELEMENT

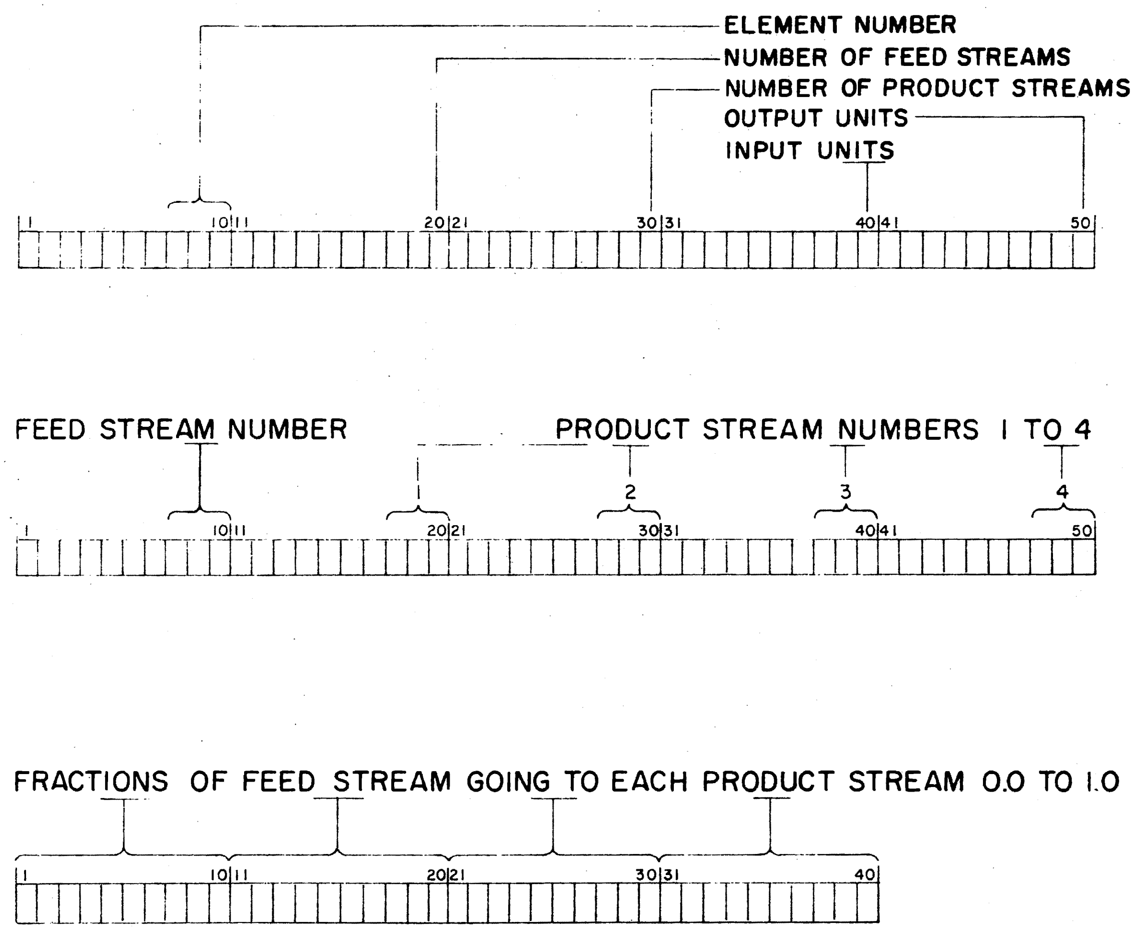


Figure 12. (Continued)

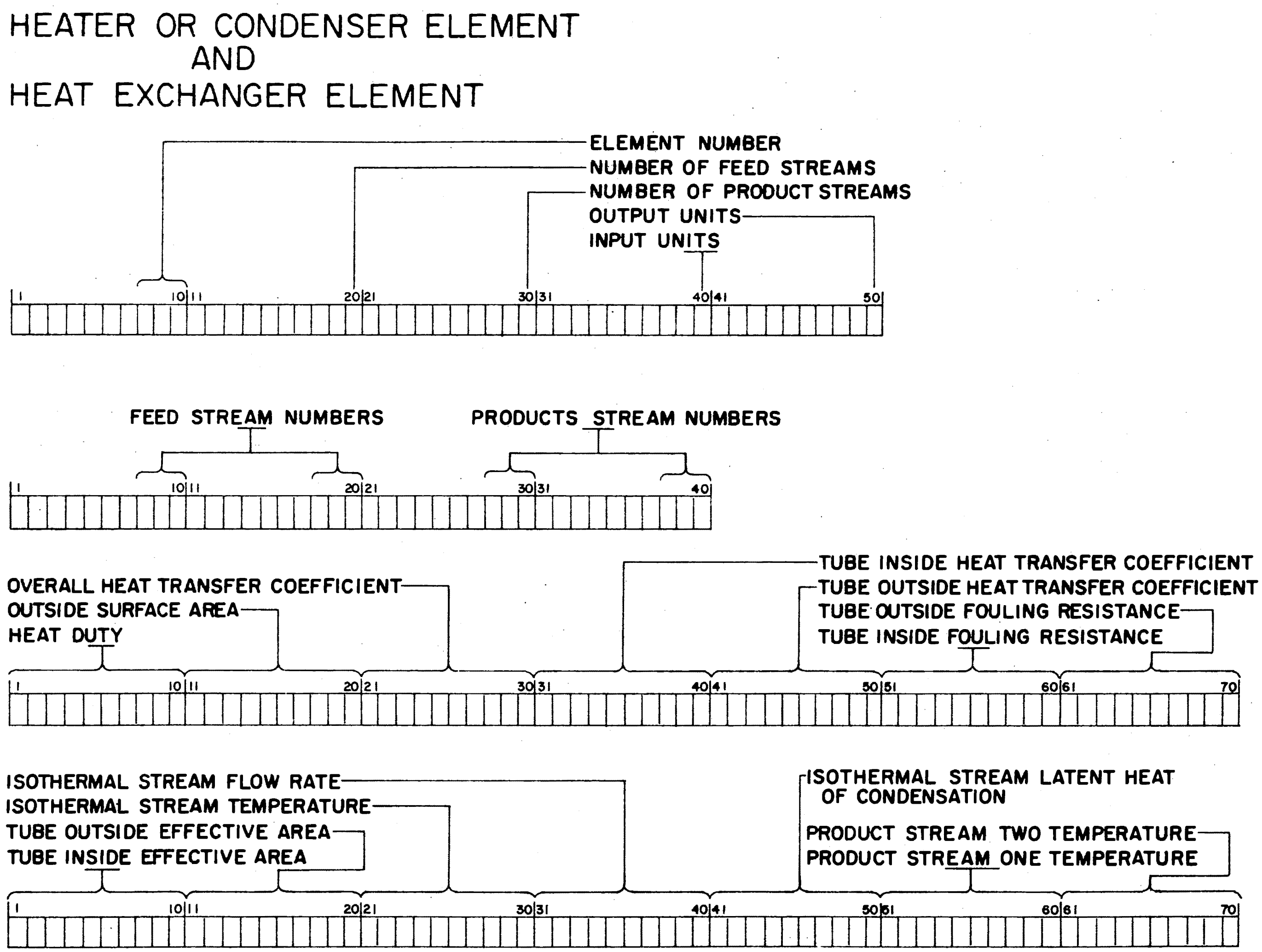


Figure 12. (Continued)

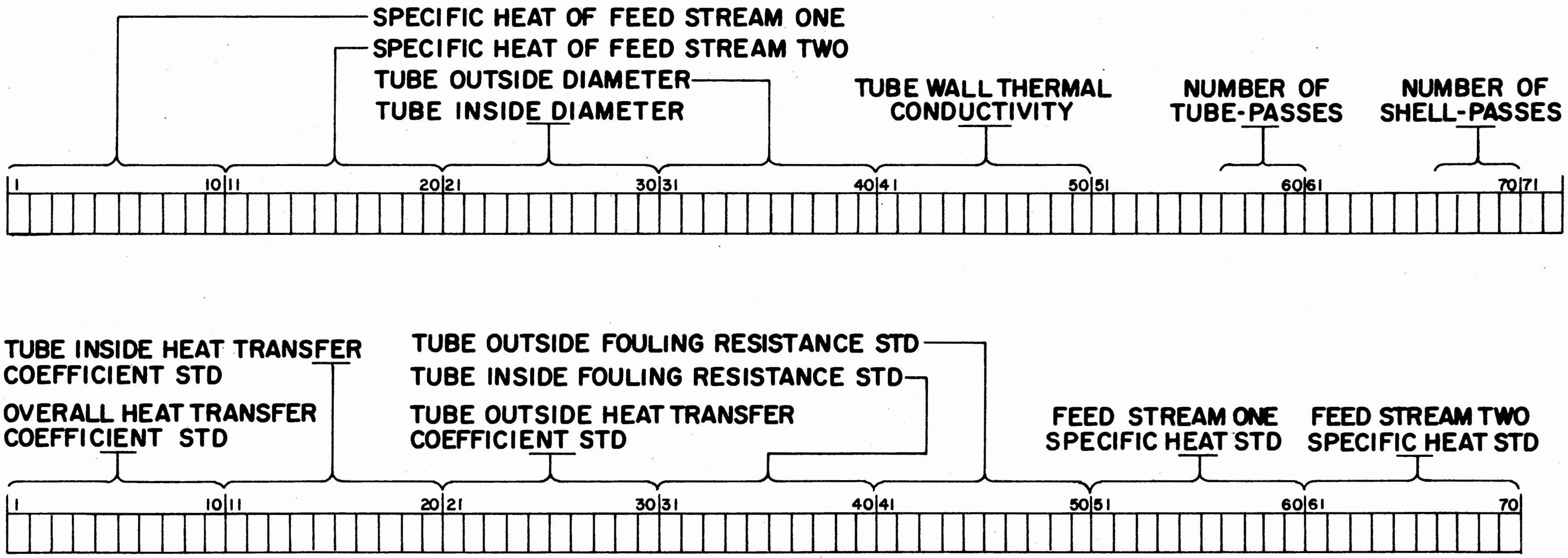
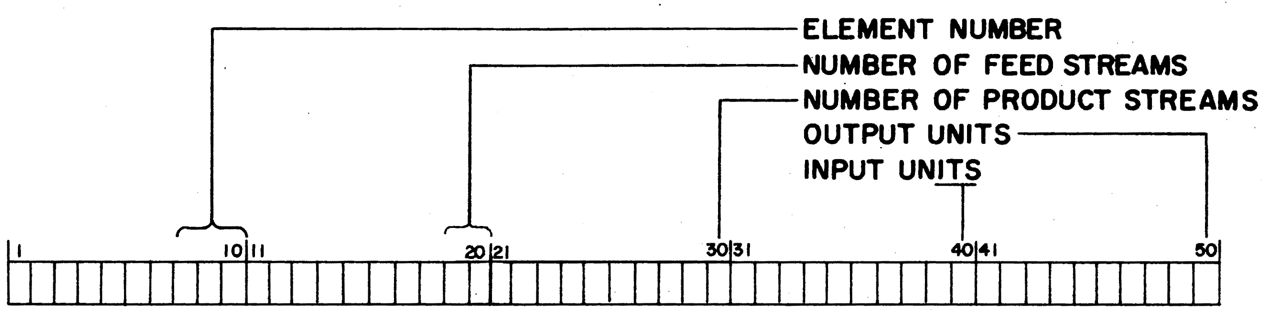


Figure 12. (Continued)

OUTPUT ELEMENT



PRODUCT STREAM NUMBERS 1 TO 20

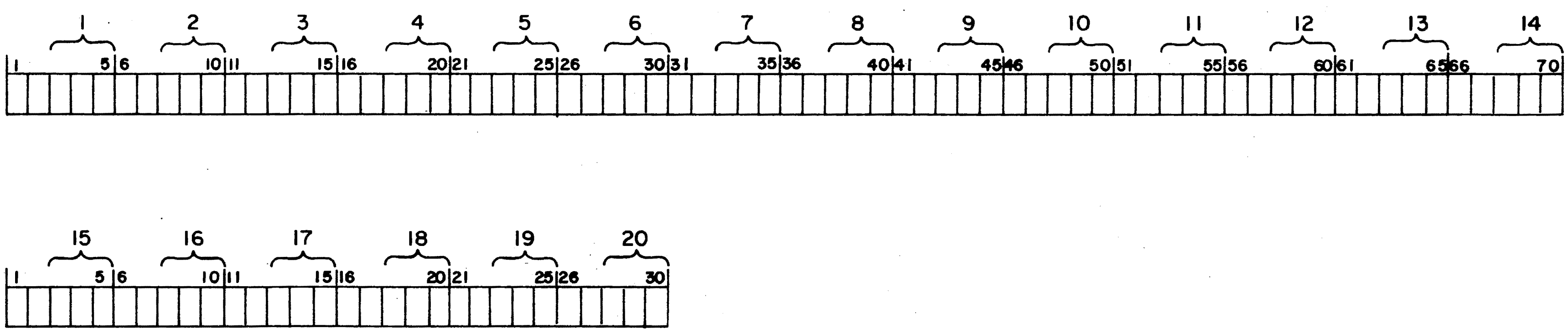


Figure 12. (Continued)

first feed stream. An integer in the range 1 to 200 is entered here.

4. Second Product Stream Number. This stream corresponds to the second feed stream. It is the hotter product stream and an integer in the range 1 to 200 is entered here.

Process Data Card 2. This card consists of seven data spaces:

1. Heat Duty: The total heat flow rate in Watts or Btu/hr is entered in this data space in the E-format if it is to be specified. If the heat duty is not specified, the space is left blank.
2. Heat Exchanger Area. This is the total surface area of the heat exchanger. It should be specified if the outlet temperatures are to be calculated and the heat duty is not specified.
3. The Overall Heat Transfer Coefficient. If the overall heat transfer coefficient is known, it should be entered here. Otherwise this space should be left blank.
4. The Tube Inside Coefficient. If the overall coefficient is not known, a value should be entered here for the tube inside coefficient.
5. The Shell Side Coefficient. If the overall coefficient is not specified, the value of the shell side coefficient should be entered here. Otherwise this data space should be left blank.
6. Tube Inside Fouling Resistance. If the inside fouling resistance is known and the overall coefficient is not specified, the value of the tube inside fouling resistance

should be entered here. Otherwise this data space is left blank.

7. Shell Side Fouling Resistance. If the outside fouling resistance is known and the overall coefficient is not specified, the value of the shell side fouling resistance is entered here. Otherwise this data space is left blank.

Process Data Card 3. This card consists of seven data spaces:

1. Tube Inside Effective Area. This data space is designated for the tube inside effective area per unit length. A value should be entered here.
2. Tube Outside Effective Area. A value for the tube outside effective area per unit length should be entered here. The tube inside and outside effective area should have the same units.
3. Isothermal Stream Temperature. For the element HEX this data space is left blank.
4. Isothermal Stream Flow Rate. This data space is left blank.
5. The Fluid Latent Heat of Condensation. This data space is left blank.
6. First Product Stream Temperature. If the outlet temperature of the colder stream is specified, its value is entered here. Otherwise this space is left blank.
7. Second Product Stream Temperature. If the outlet temperature of the hotter stream is specified, its value is entered here. Otherwise this space is left blank.

Process Data Card 4. This card consists of seven data spaces:

1. Cold Stream Specific Heat. As in the HRCR element, if a

pseudo-specific heat of the colder fluid, or an average value is needed, its value is entered here. Otherwise this data space is left blank.

2. Hot Stream Specific Heat. The pseudo or average specific heat for the hotter stream is entered here if required. Otherwise this data space is left blank.

3. Tube Inside Diameter. If the resistance due to the tube wall is to be calculated and the overall heat transfer coefficient is not specified, a value for the tube inside diameter in feet or meters is entered here. Otherwise this space is left blank.

4. Tube Outside Diameter. The same rules applied to tube inside diameter also apply to the outside diameter.

5. Tube Wall Thermal Conductivity.

6. Flow Arrangement. An integer number 1, 2, or 3 is entered here for the type of flow arrangement specified. The integer number entered in this data space indicates the following arrangement

Integer	Flow Arrangement
1	Cocurrent flow
2	Countercurrent flow
3	1-n, 2-2n, etc. (n=2,4,6,...)

7. Number of Shell Passes. The number of shell passes in series should be entered here. This number is an integer and always greater than zero.

Process Data Card 5. There are seven data spaces in this card. These spaces are designated for the standard deviations of the parameters; overall, tube inside, and shell side coefficients, tube inside, shell side resistances, cold and hot fluids specific heats respectively.

If Monte Carlo simulation is not specified for the process, this card is included as a blank card.

Process Element Output

Process Data Card 1. This card contains fourteen data spaces. Each space filled with a feed stream number. If there are less than 14 feed streams, the remaining data spaces are left blank.

Process Data Card 2. This card contains six data spaces as shown in Figure 12. Each space is filled with a feed stream number. If there are 14 or less feed streams, this card should be included in the data set but left blank. It should be noted here that all integer numbers should be adjusted to the right when entered in the appropriate space and each variable is entered in the appropriate format specified in the program.

CHAPTER IV

DEMONSTRATION PROBLEM

Problem Description

To demonstrate the effect of uncertainties in feed stream conditions and heat exchanger parameters, and to illustrate the use of the computer program, a typical problem from industry is chosen (18) (28) for this purpose. The problem is a crude preheat exchanger train for a distillation unit. A crude charge at 94^{o}F temperature is to be preheated up to 385^{o}F before it is fed to the flash tower. The preheating is done by utilizing the overhead and side streams of the fractionation towers. The bottom product of the flash tower is also heated from a temperature of 347^{o}F up to 477^{o}F before it is fed to the crude stabilizer. A schematic diagram of the optimized design for the preheat train is presented in Figure 13. It is important that the specified temperatures for the crude feed to desalter, the crude feed to flash tower and the hot crude feed to the stabilizer be achieved and that the variation be within a small range of the nominal values. If, for example, the temperature were higher than expected, partial vaporization of the crude might occur inside some of the heat exchangers, which will have an effect on the efficient operation of the system of heat exchangers.

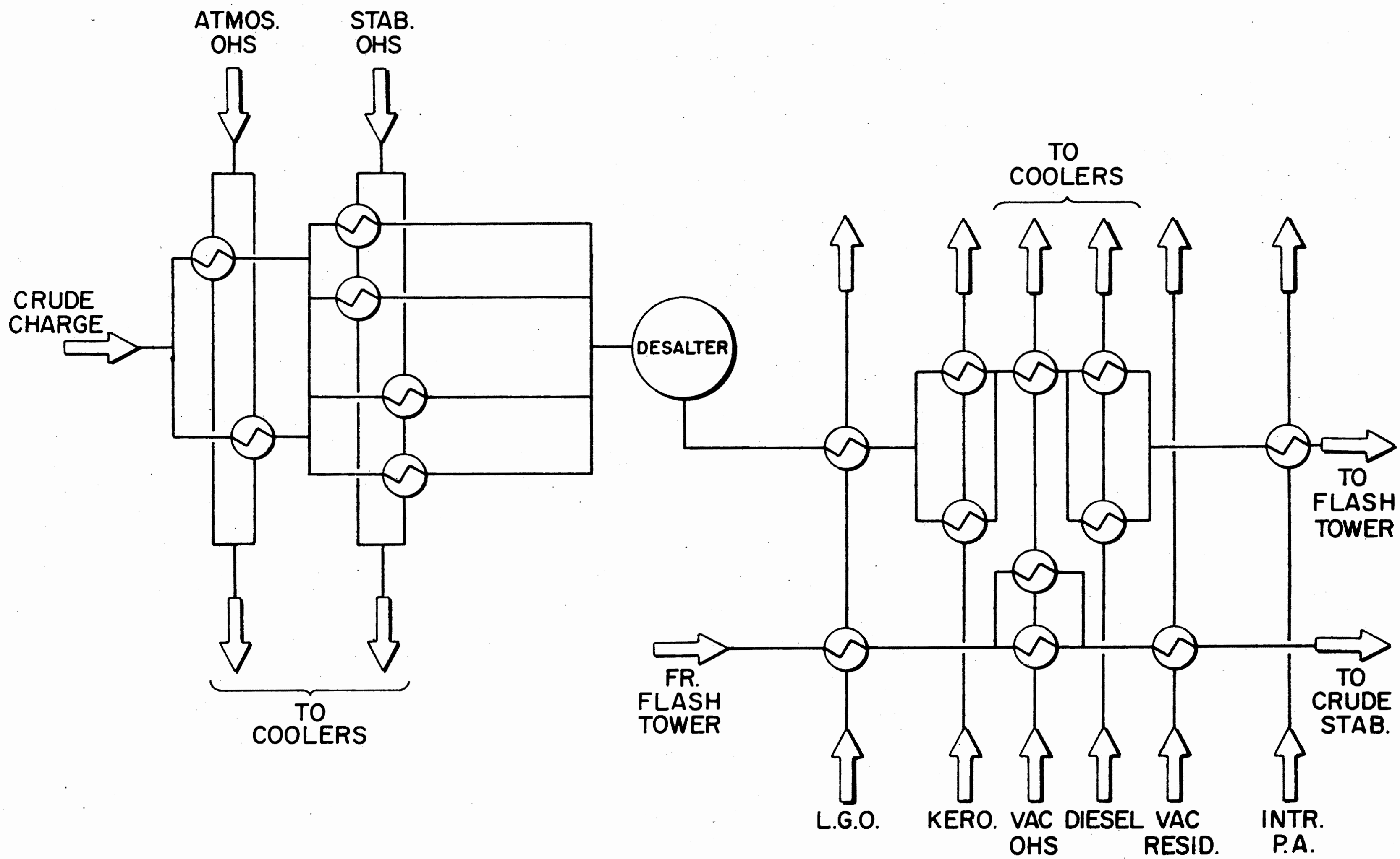


Figure 13. Schematic Diagram of the Optimized Design for the Crude Preheat Train

When the temperature change for any stream is relatively large in a heat exchanger the difference in specific heats between inlet and outlet temperature becomes significant and the assumption of constant specific heat will not apply.

In order to rectify this, the arithmatic average specific heat between the inlet and outlet temperatures is used for each heat exchanger when the temperature change warrants it.

Problem Solution

First, each stream in and out of an element in the process is assigned an integer number in the range of 1 to 200 as shown in Figure 14. Then, adding the input and output elements to the system, each element is also assigned an integer number in the range of 1 to 100 as shown in Figure 15. The input data for the feed streams to the system is given in Table III. The heat exchanger heat transfer coefficients, fouling resistances, sizes and flow arrangements are specified in Table IV. Simulation of the heat exchanger system was then carried out for both the deterministic and stochastic models. Results of the calculations for the effluent stream temperatures are presented in Table V. The nominal values in Table V indicate the deterministic solution based upon the expected values for variables and parameters given in Tables III and IV. Fluctuation in feed stream conditions and heat exchanger coefficients and fouling resistances were not considered in this case. Another simulation of the system using the stochastic model has been made where uncertainties in input data were taken into consideration. Two cases were considered. In the first

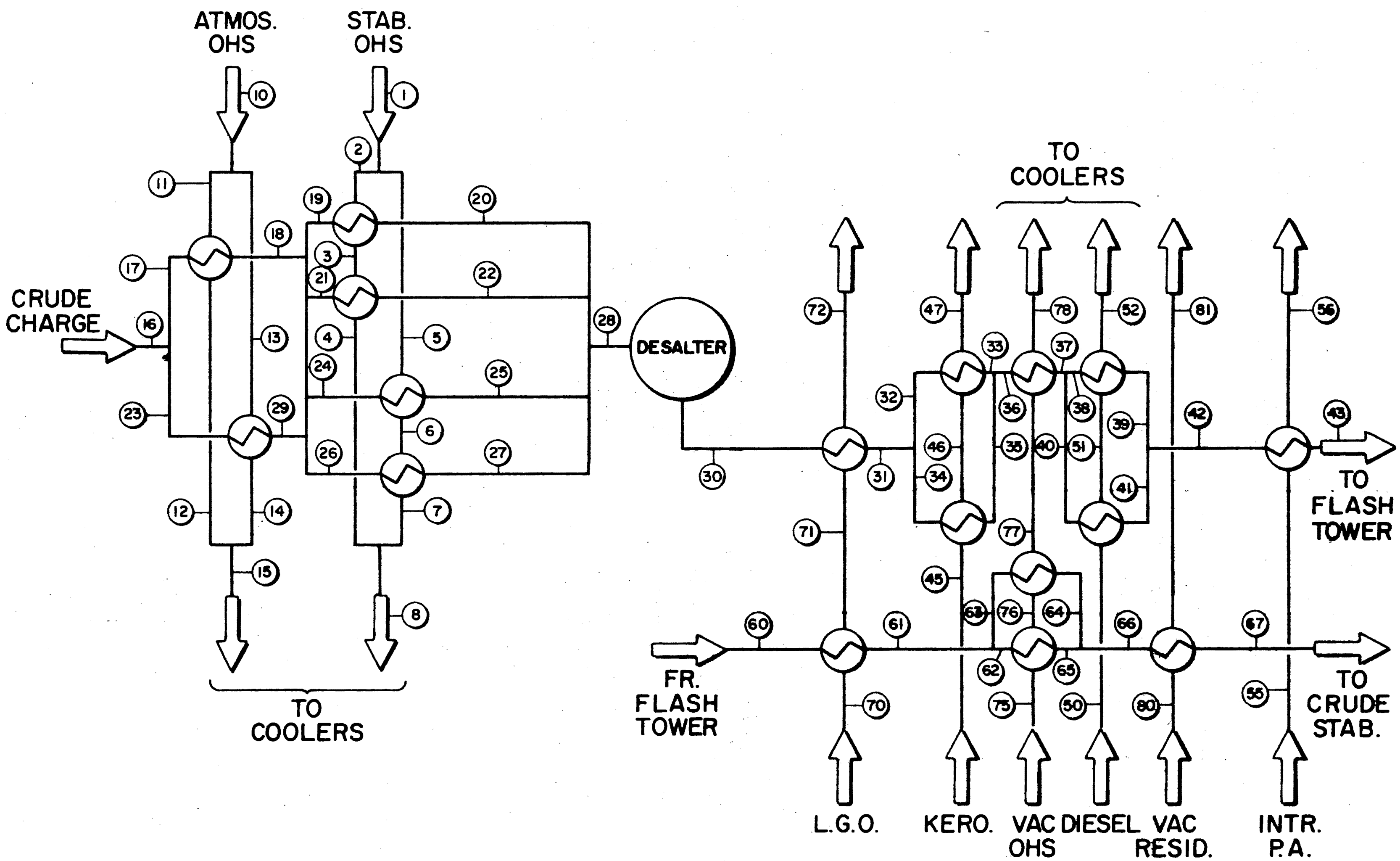


Figure 14. Stream Number Assignment for the Crude Preheat Train

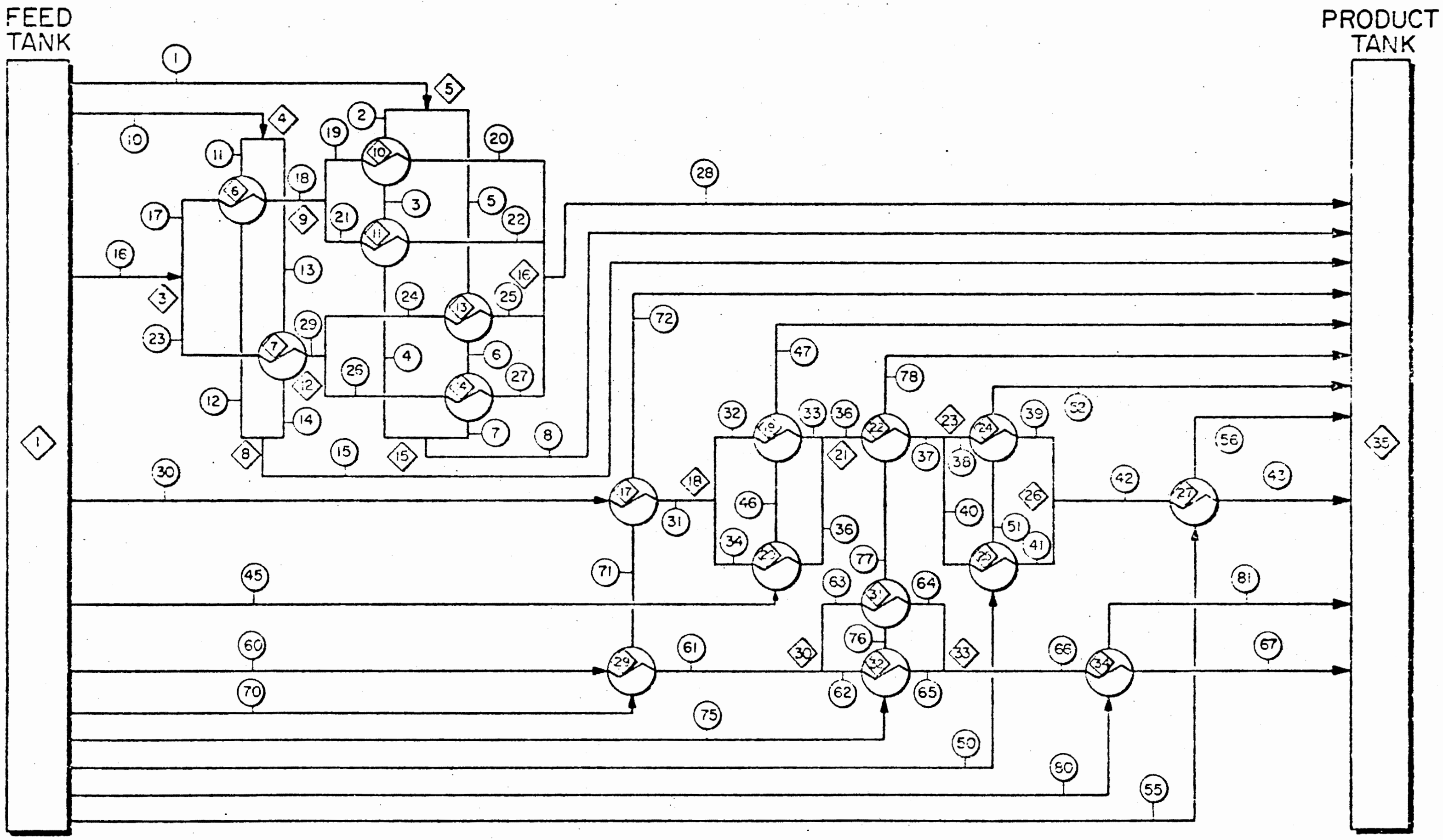


Figure 15. Element Number Assignment for the Crude Preheat Train with Added Feed and Product Tanks

TABLE III

FEED STREAM CONDITIONS

Variable \ Feed Stream Number	1	10	16	30	45	50	55	60	70	75	80
Flow Rate lb/hr	171,310	10,380	712,670	712,670	69,062	94,220	361,150	634,300	91,216	144,039	86,166
Temperature ^oF	284.0	306.0	94.0	226.0	413.0	491.0	509.0	367.0	579.0	631.0	642.0
Specific Heat Btu/lb ^oF	2.943*	16.433*	0.550	0.550	0.668	0.657	0.640	0.626	0.70	1.20*	0.730

* Pseudo Specific Heat

TABLE IV

SPECIFIED VARIABLES FOR EACH HEAT EXCHANGER

Variable \ Heat Exchanger Number	6	7	10	11	13	14	17	20
Area Ft^2/Shell Pass	1650.0	1650.0	1420.0	1278.0	1420.0	1278.0	2015.0	1060.0
Tube Wall Thermal Conductivity Btu/ft. hr^{o}F	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
Tube Inside Heat Transfer Coefficient, Btu/hrft^{2o}F	450.0	450.0	460.0	460.0	460.0	460.0	160.0	222.2
Shell Side Heat Transfer Coefficient, Btu/hrft^{2o}F	295.0	295.0	150.0	140.0	150.0	140.0	120.0	192.3
Tube Inside Fouling Resistance, hrft^{2o}F/Btu	0.00375	0.00375	0.00423	0.00450	0.00423	0.00450	0.00780	0.00300
Shell Side Fouling Resistance, hrft^{2o}F/Btu	0.00160	0.00160	0.00300	0.00320	0.00300	0.00320	0.00550	0.00160
Effective Tube Inside Area Ft^2/Ft	0.2048	0.2048	0.2048	0.2048	0.2048	0.2048	0.2048	0.2048
Effective Tube Outside Area Ft^2/Ft	0.2618	0.2618	0.2618	0.2618	0.2618	0.2618	0.2618	0.2618
Tube Inside Diameter Ft	0.06517	0.06517	0.06517	0.06517	0.06517	0.06517	0.06517	0.06517
Tube Outside Diameter Ft	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333
Flow Arrangement*	3	3	3	3	3	3	3	3
Number of Shell Passes	1	1	2	1	2	1	2	1
Specific Heat of the Cold Fluid**, Btu/lb^{o}F	0.493	0.493	0.5020	0.5020	0.5020	0.5020	0.550	0.580
Specific Heat of the Hot Fluid**, Btu/lb^{o}F	$16.433^{\dagger}$	$16.433^{\dagger}$	$2.9430^{\dagger}$	$2.6412^{\dagger}$	$2.9430^{\dagger}$	$2.6412^{\dagger}$	0.653	0.668

TABLE IV (Continued)

Variable \ Heat Exchanger Number	19	22	24	25	27	29	31	32	34
Area Ft^2/Shell Pass	1107.0	2496.0	659.0	1825.0	935.0	1440.0	3272.0	1610.0	82[illegible].0
Tube Wall Thermal Conductivity Btu/ft hr ^oF	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
Tube Inside Heat Transfer Coefficient, Btu/hrft^{2o}F	200.0	333.3	312.5	284.0	413.0	385.0	200.0	200.0	327.0
Shell Side Heat Transfer Coefficient, Btu/hrft^{2o}F	154.0	285.7	357.1	196.0	600.0	290.0	181.8	142.9	380.0
Tube Inside Fouling Resistance, hrft^{2o}F/Btu	0.00400	0.00250	0.00206	0.00500	0.00150	0.00246	0.00270	0.00270	0.00200
Shell Side Fouling Resistance, hrft^{2o}F/Btu	0.00300	0.00163	0.00180	0.00470	0.00066	0.00150	0.00100	0.00100	0.00166
Effective Tube Inside Area Ft^2/Ft	0.2048	0.2048	0.2048	0.2048	0.2048	0.2048	0.2048	0.2048	0.2048
Effective Tube Outside Area Ft^2/Ft	0.2618	0.2618	0.2618	0.2618	0.2618	0.2618	0.2618	0.2618	0.2618
Tube Inside Diameter Ft	0.06517	0.06517	0.06517	0.06517	0.06517	0.06517	0.06517	0.06517	0.06517
Tube Outside Diameter Ft	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333
Flow Arrangement*	3	3	3	3	3	3	3	3	3
Number of Shell Passes	1	1	1	1	2	1	1	1	1
Specific Heat of the Cold Fluid**, Btu/lb^{o}F	0.560	0.585	0.594	0.600	0.566	0.626	0.668	0.668	0.70
Specific Heat of the Hot Fluid**, Btu/lb^{o}F	0.595	0.661	0.612	0.657	0.640	0.70	1.200+	1.200+	0.73

* The integer numbers entered in the table for flow arrangements indicate the following flow arrangement
1) Cocurrent Flow 2) Counter Current Flow 3) Co-Counter Current Flow

** An arithmetic average specific heat is computed for each feed stream to a heat exchanger whenever there is a relatively large change in the temperature of the stream between the inlet and outlet.

\+ Pseudo specific heat

TABLE V

RESULT OF OUTLET TEMPERATURE CALCULATIONS

Outlet Stream Number	Nominal Temperature (Calc) °F	Number of Simulations	1% and 5% Coeff. of Variation*		5% and 10% Coeff. of Variation**	
			Mean Temp. (Calc) °F	Standard Deviation °F	Mean Temp. (Calc) °F	Standard Deviation °F
8	233.97	500	233.696	3.410	233.252	10.389
15	170.10	500	169.767	4.251	169.202	10.344
28	228.02	500	227.695	3.813	227.136	10.414
43	384.92	500	384.915	5.882	385.056	15.274
47	266.79	500	267.034	3.189	267.834	10.905
52	328.71	500	329.006	4.716	329.722	11.953
56	405.90	500	405.825	5.603	405.790	16.309
67	476.92	500	477.069	5.201	477.306	16.858
72	254.31	500	254.706	3.788	255.697	11.937
78	308.11	500	308.539	4.751	309.608	12.291
81	521.81	500	521.898	5.473	522.272	17.661

* Coefficient of variation ($\frac{\sigma}{\mu}$ x 100) is 1 percent for inlet temperatures and 5 percent for flow rates, heat transfer coefficients and fouling resistances.

** Coefficient of variation is 5 percent for the inlet temperatures and 10 percent for flow rates, heat transfer coefficients, and fouling resistances.

case the coefficients of variations chosen were 1% for the inlet temperatures and 5% for the flow rates, heat transfer coefficients, and fouling resistances. These coefficient of variation estimates are conservative and would illustrate the significance of uncertainties in input data and their effect on output temperatures. In the second case, the coefficients of variations were taken to be 5% and 10% respectively.

For each one of the two cases mentioned above two runs were made. One run is to calculate the statistics for the outlet stream temperatures and in the other the statistics for the individual heat exchanger areas were calculated. The calculation of the areas was performed by fixing the outlet temperature for each heat exchanger in the system according to the predetermined nominal temperature.

Results of the calculations for both cases are shown in Table V, VI and VII. The cumulative probability curves for the outlet temperatures are also included (Figures 16-26) as part of the standard output for the computer program developed in Chapter III. These curves are the results of 500 simulations for the second case.

The crude charge effluent stream (number 43) is found to have an average temperature of 384.915^{o}F and a standard deviation of 5.882^{o}F in the first case and an average temperature of 385.056^{o}F and standard deviation of 15.274^{o}F for the second case as shown in Table V. The average temperature in both cases for 500 simulations is found to be very close to the nominal value and the magnitude of the uncertainties in input data is reflected in the calculated standard deviation in each case.

Tables VI and VII show the outcome of the area calculation for each heat exchanger for 500 simulations in both cases. The nominal area listed in the tables for each exchanger is the area required to calculate the nominal temperatures listed in Table V. For each exchanger the outlet temperature of the cold stream is assigned a deterministic value calculated from the deterministic simulation and the outlet temperature of the hot stream is then calculated from the heat balance between the two streams. Two situations arise when calculating the area of a heat exchanger using the stochastic model. The first one is when the cold stream inlet temperature generated is equal to or greater than the specified outlet temperature. In this case the exchanger is not needed and the area required is zero. The other situation is when the outlet temperature of the hot stream calculated is less than or equal to the inlet temperature of the cold stream or the specified outlet temperature of the cold stream is greater than or equal to the generated inlet temperature of the hot stream. In this case the specified cold stream outlet temperature cannot be accomplished even with an infinite area. Both situations are listed in Tables VI and VII in addition to the mean and standard deviation of the area for the simulations where the area is greater than zero but finite.

The effect of the number of simulations on the outcome of the statistics of the effluent streams has been tested and the results are shown in Table VIII for effluent streams number 43 and 67. These two streams were chosen because they reflect the composite effect of more heat exchanger elements than the others. It is shown, as expected, that the more the number of simulations the closer the sample mean to

TABLE VI

RESULTS OF HEAT EXCHANGER AREA CALCULATIONS FOR THE CASE OF 1% AND 5% COEFFICIENT OF VARIATIONS

Heat Exchanger Number	Nominal Total Area Ft^2	Total Number of Simulations	Number of Simulations Where Heat Exchanger is Not Needed	Number of Simulations Where Outlet Temperature Cannot be Met	Mean Area for the Remaining Simulations Ft^2	Standard Deviation Ft^2
6	1651.610	500	--	1	1733.760	341.599
7	1651.610	500	--	1	1738.120	345.848
10	2839.120	500	--	-	2876.666	268.492
11	1275.020	500	--	-	1297.577	151.430
13	2839.120	500	--	-	2866.766	271.916
14	1275.020	500	--	-	1297.369	150.562
29	1416.310	500	--	56	1477.141	652.860
32	1610.740	500	--	-	1621.165	134.784
31	3325.040	500	--	3	3519.823	959.526
34	813.770	500	--	-	824.835	109.480
17	3972.800	500	--	148	3362.662	1052.395
20	1056.630	500	--	-	1075.314	149.122
19	1095.340	500	--	56	1175.106	535.302
22	2516.640	500	--	69	2554.318	860.071
25	1832.140	500	--	-	1884.039	292.771
24	668.600	500	--	28	760.732	379.575
27	1868.450	500	--	-	1899.567	218.071

TABLE VII

RESULTS OF HEAT EXCHANGER AREA CALCULATIONS FOR THE CASE OF 5% AND 10% COEFFICIENT OF VARIATIONS

Heat Exchanger Number	Nominal Total Area Ft^2	Total Number of Simulations	Number of Simulations Where Heat Exchanger is Not Needed	Number of Simulations Where Outlet Temperature Cannot be Met	Mean Area for the Remaining Simulations Ft^2	Standard Deviation Ft^2
6	1651.610	500	--	67	1774.608	743.256
7	1651.610	500	--	67	1781.471	742.162
10	2839.120	500	--	115	2693.821	619.050
11	1275.020	500	--	4	1482.068	763.129
13	2839.120	500	--	115	2672.297	630.487
14	1275.020	500	--	4	1484.085	778.707
29	1416.310	500	36	189	940.319	811.875
32	1610.740	500	--	1	1731.052	512.562
31	3325.040	500	--	112	3285.611	1763.203
34	813.770	500	--	32	909.510	453.435
17	3972.800	500	8	210	1801.689	1367.325
20	1056.630	500	--	30	1164.127	513.188
19	1095.340	500	--	153	958.088	619.386
22	2516.640	500	--	157	2185.177	1090.763
25	1832.140	500	--	46	2047.865	932.166
24	668.600	500	--	142	683.624	510.652
27	1868.450	500	--	41	1949.288	583.352

TABLE VIII

EFFECT OF NUMBER OF SIMULATIONS ON THE STATISTICS OF THE CRUDE EFFLUENT STREAM TEMPERATURES

Effluent Stream Number	Nominal Temperature °F	Number of Simulations	1% and 5% Coeff. of Variation* Mean Temperature °F	1% and 5% Coeff. of Variation* Standard Deviation °F	5% and 10% Coeff. of Variation** Mean Temperature °F	5% and 10% Coeff. of Variation** Standard Deviation °F
43	384.920	200	374.248	5.369	365.799	12.548
		300	375.540	5.065	365.827	12.168
		400	382.577	5.893	382.725	14.517
		500	384.915	5.882	385.056	15.274
67	476.920	200	480.411	5.448	490.014	18.684
		300	481.496	5.342	497.386	16.839
		400	475.021	5.283	466.896	16.774
		500	477.069	5.201	477.306	16.858

* Coefficient of variation is 1 percent for inlet temperatures and 5 percent for flow rates, heat transfer coefficients and fouling resistances.

** Coefficient of variation is 5 percent for inlet temperatures and 10 percent for flow rates, heat transfer coefficients and fouling resistances.

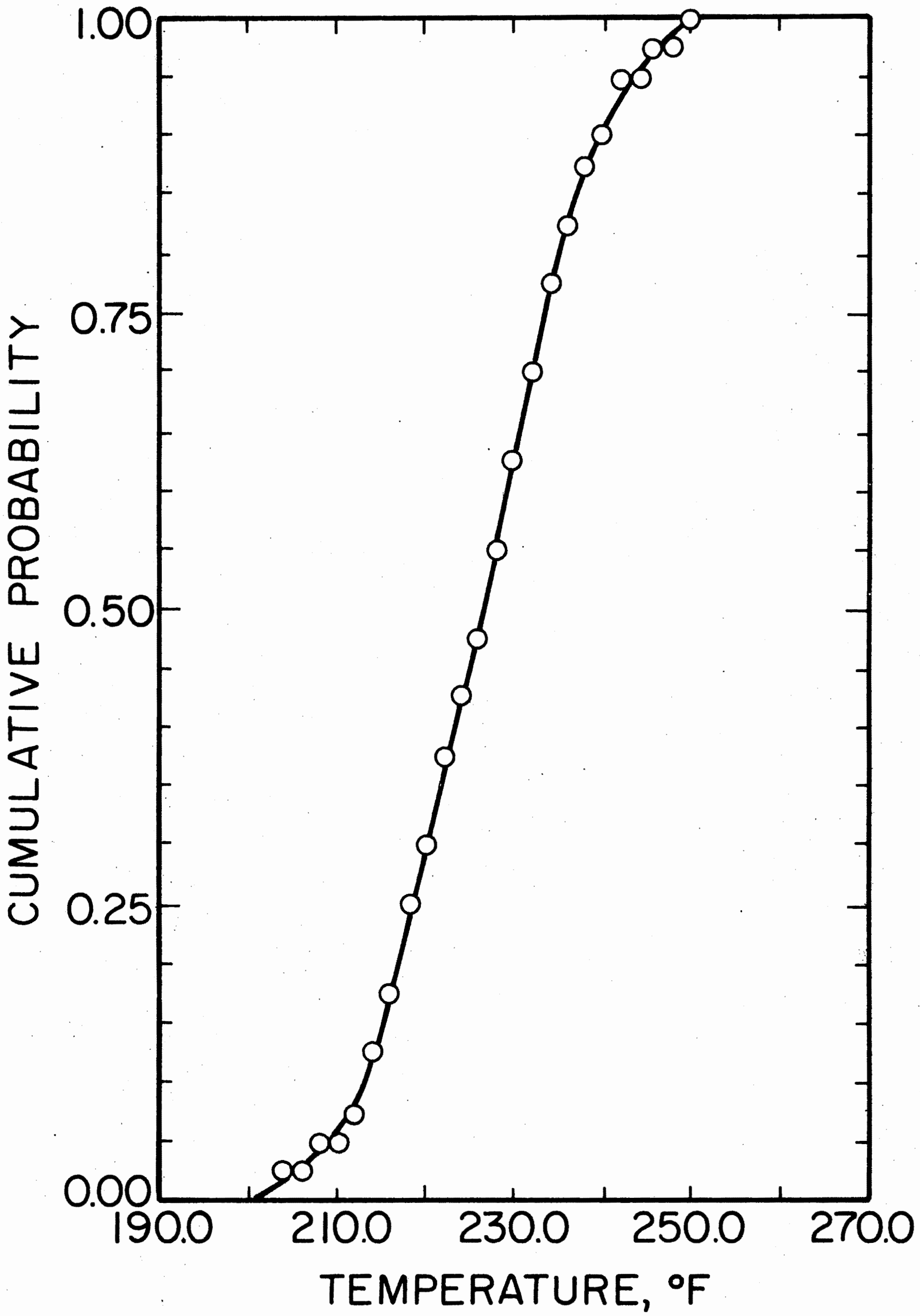


Figure 16. Effluent Stream Number 28; Temperature Cumulative Probability Curve for the Case of 5% and 10% Coefficients of Variation

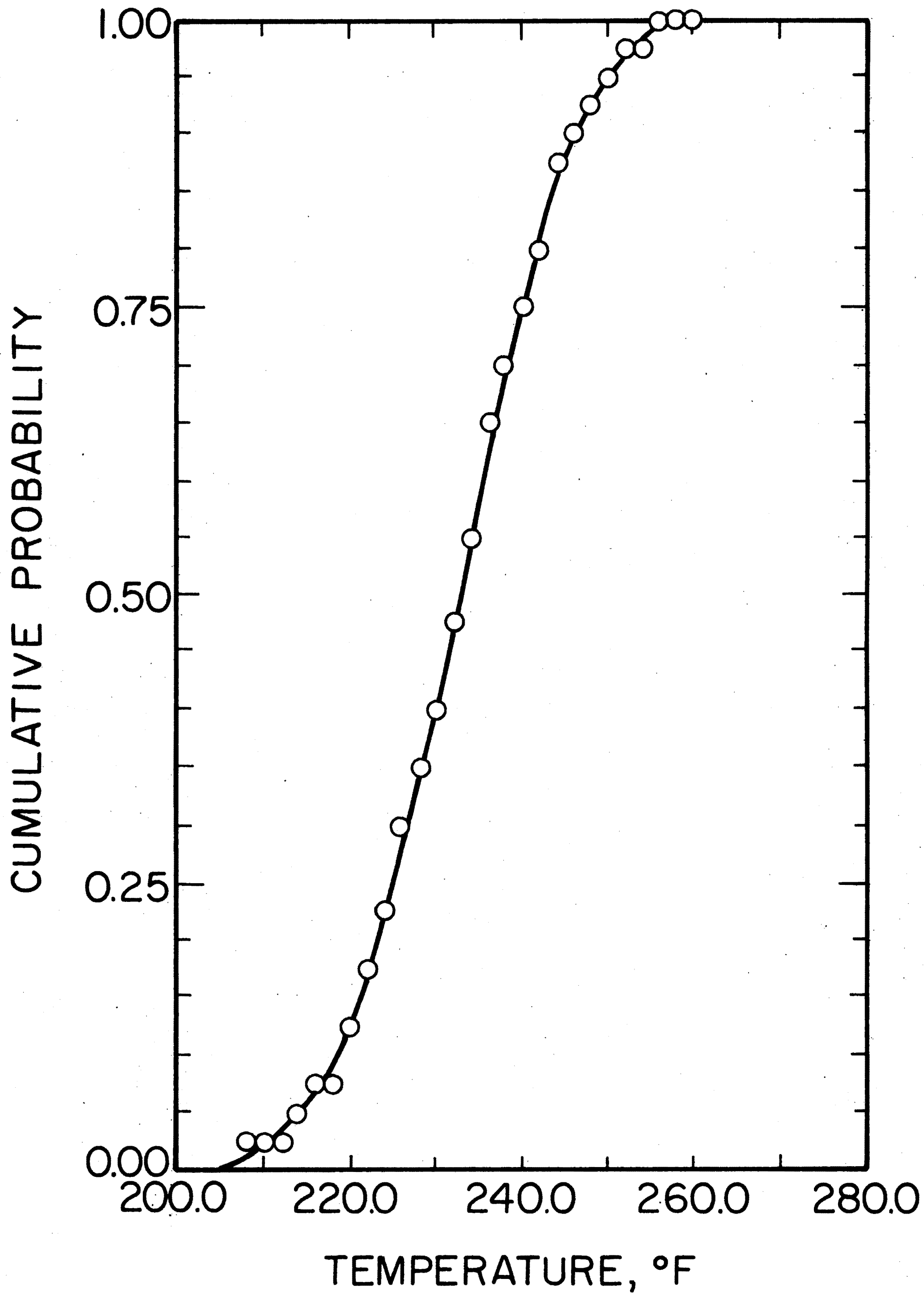


Figure 17. Effluent Stream Number 8; Temperature Cumulative Probability Curve for the Case of 5% and 10% Coefficients of Variation

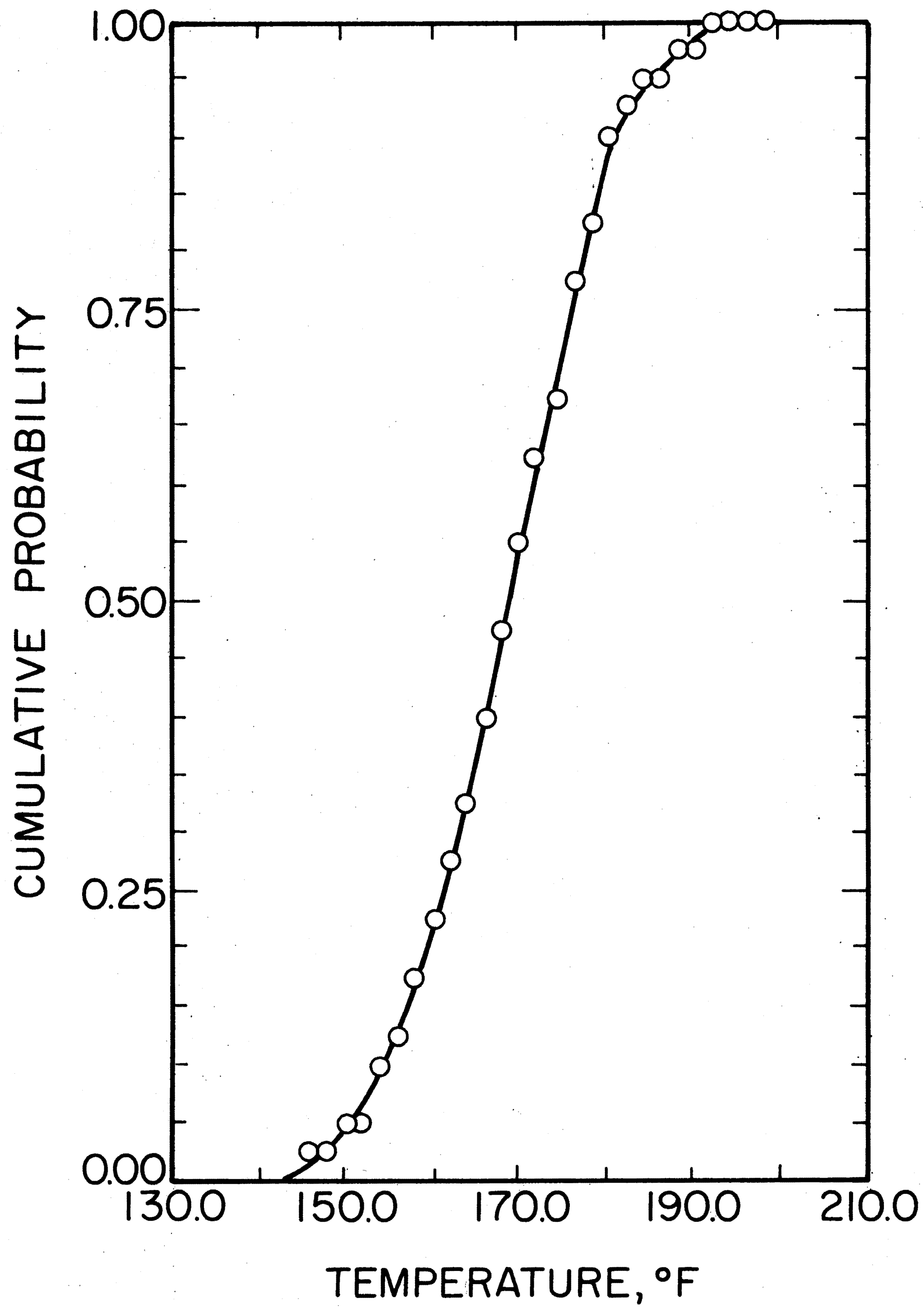


Figure 18. Effluent Stream Number 15; Temperature Cumulative Probability Curve for the Case of 5% and 10% Coefficients of Variation

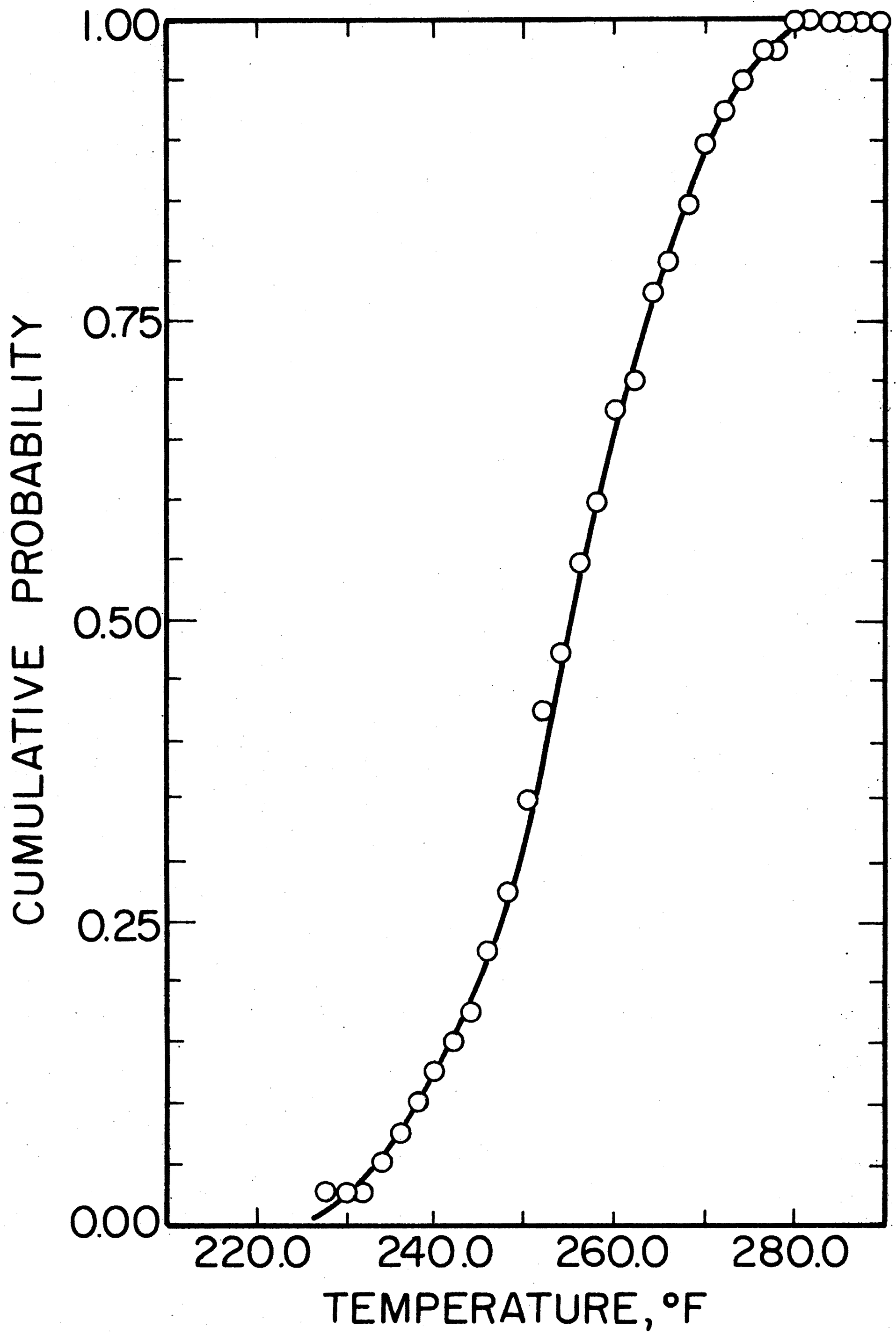


Figure 19. Effluent Stream Number 72; Temperature Cumulative Probability Curve for the Case of 5% and 10% Coefficients of Variation

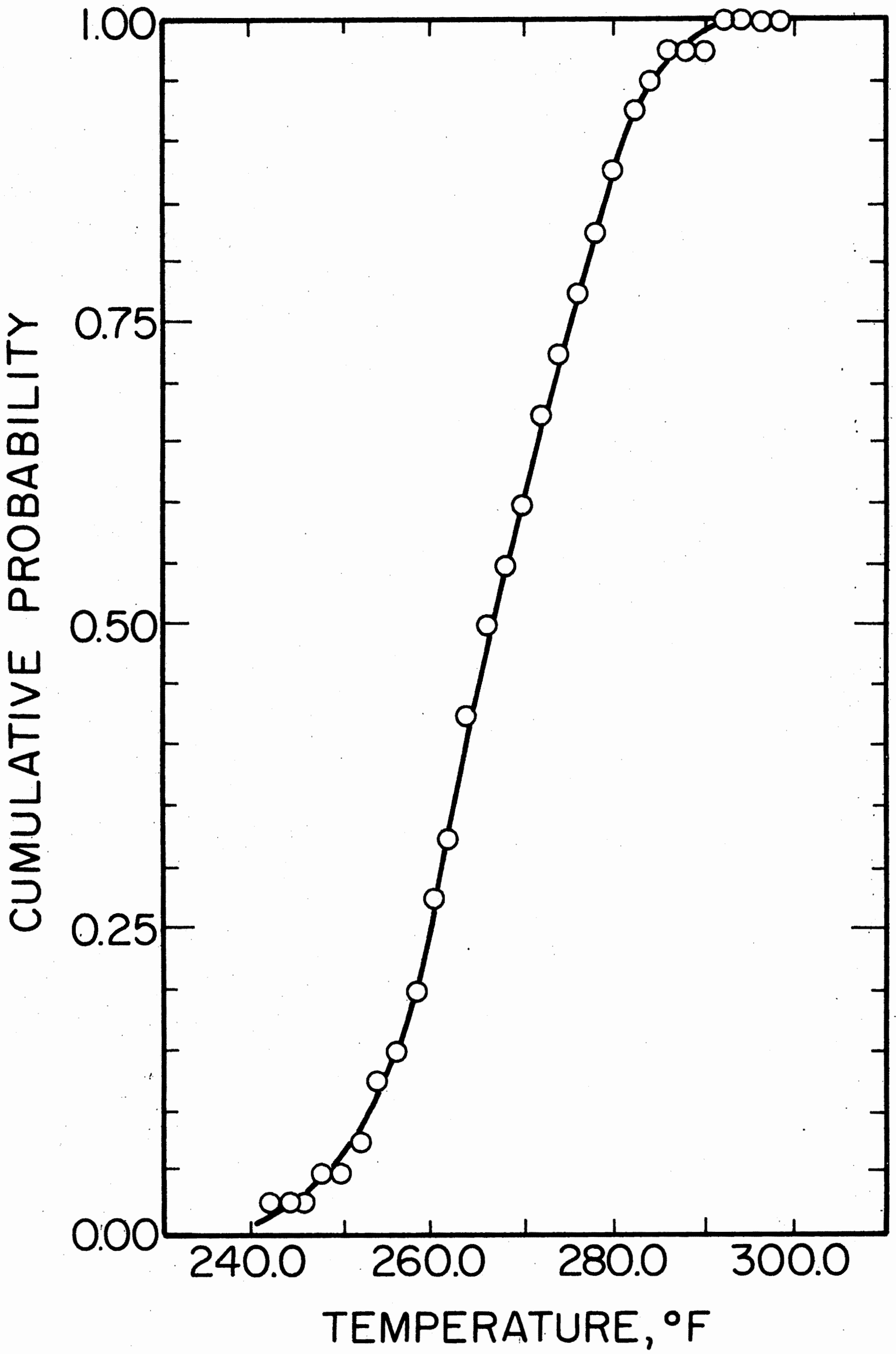


Figure 20. Effluent Stream Number 47; Temperature Cumulative Probability Curve for the Case of 5% and 10% Coefficients of Variation

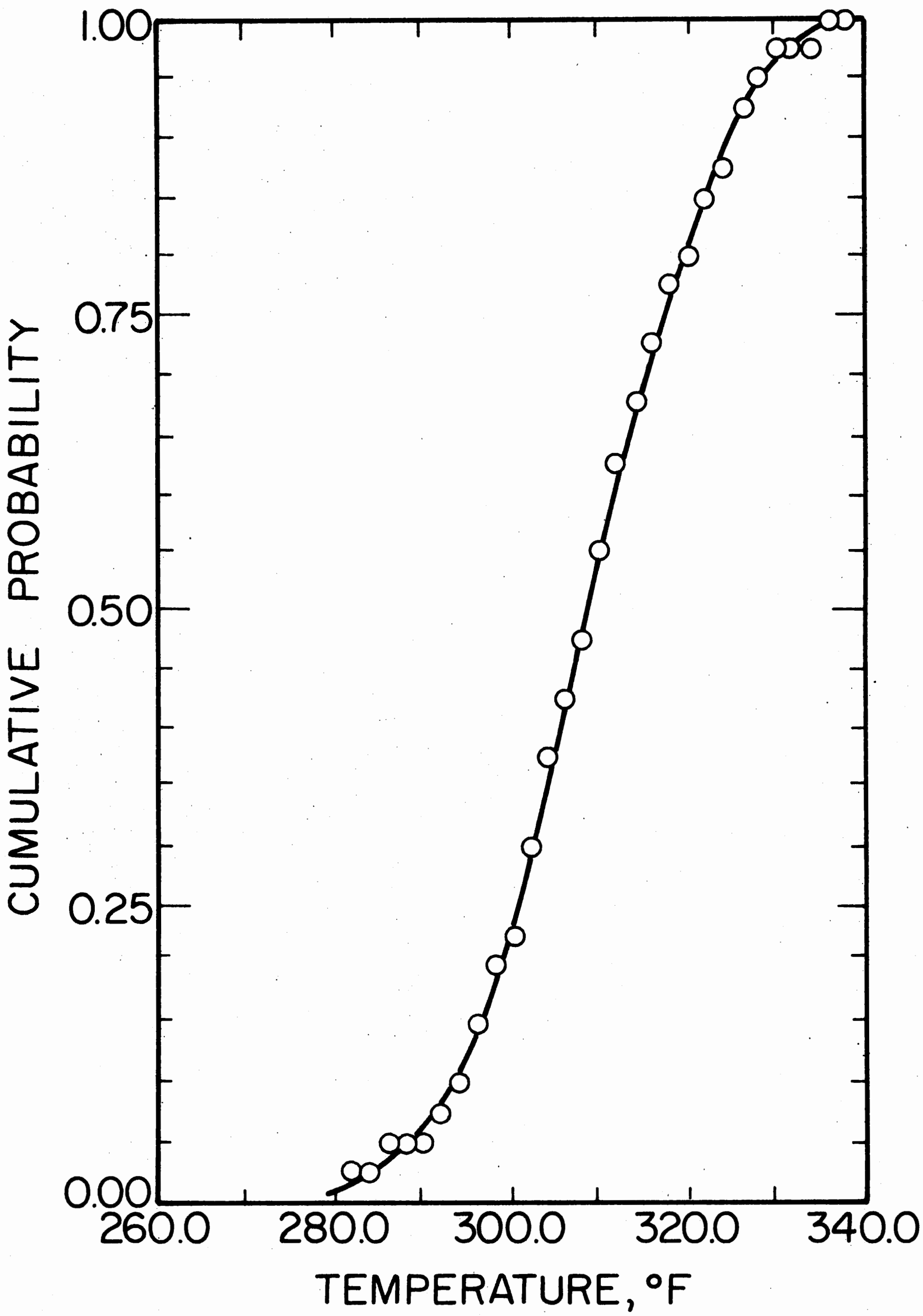


Figure 21. Effluent Stream Number 78; Temperature Cumulative Probability Curve for the Case of 5% and 10% Coefficients of Variation

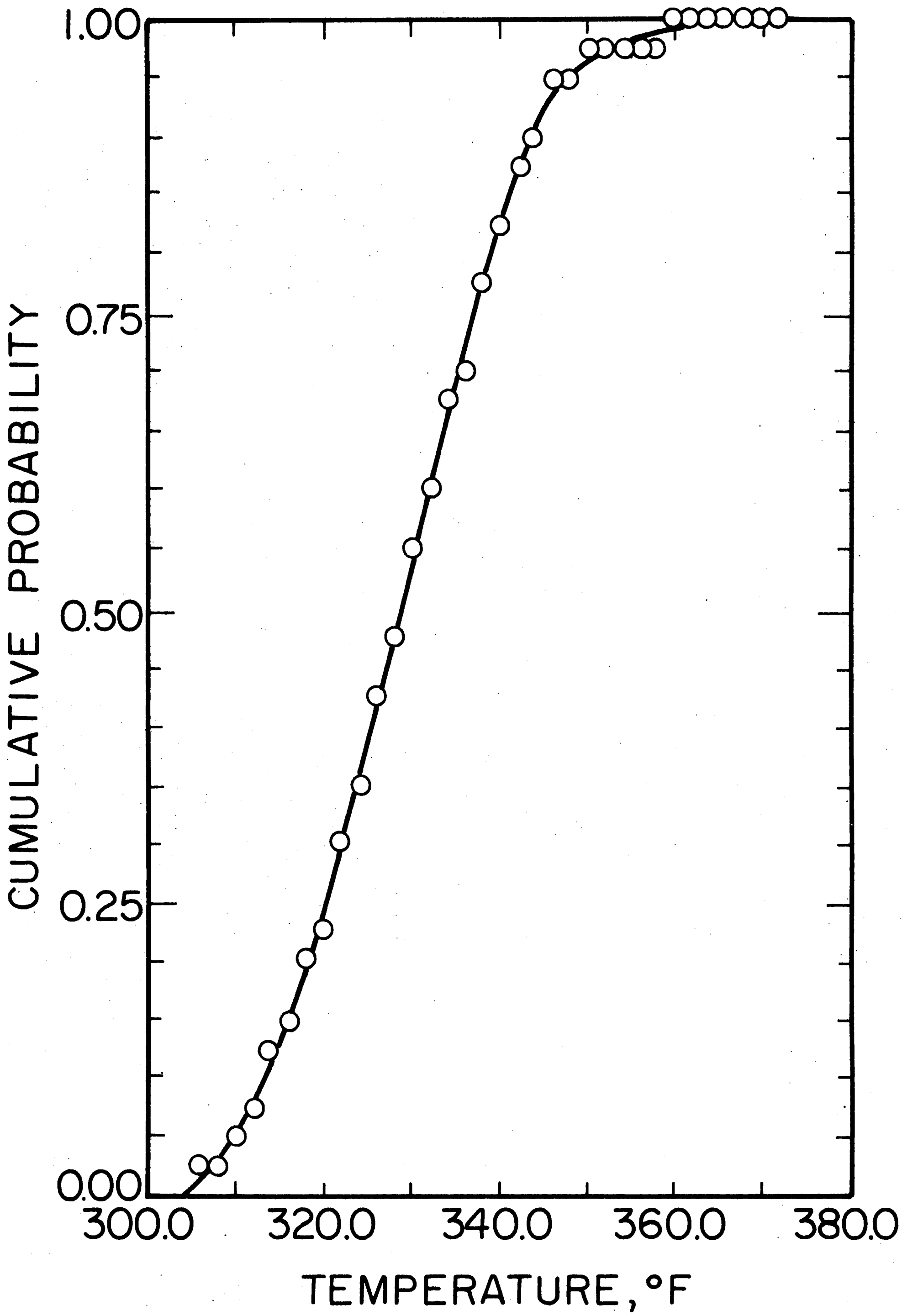


Figure 22. Effluent Stream Number 52; Temperature Cumulative Probability Curve for the Case of 5% and 10% Coefficients of Variation

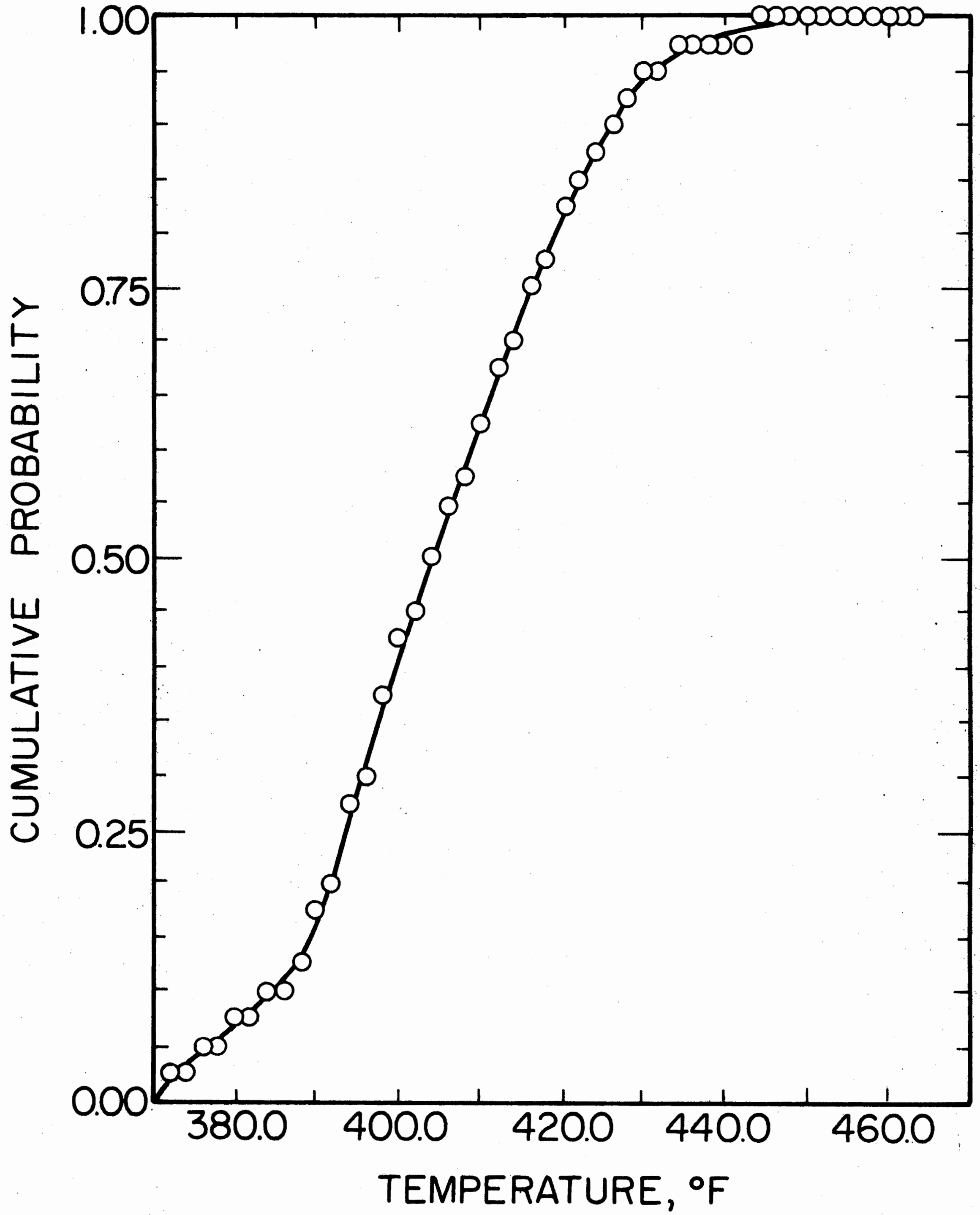


Figure 23. Effluent Stream Number 56; Temperature Cumulative Probability Curve for the Case of 5% and 10% Coefficients of Variation

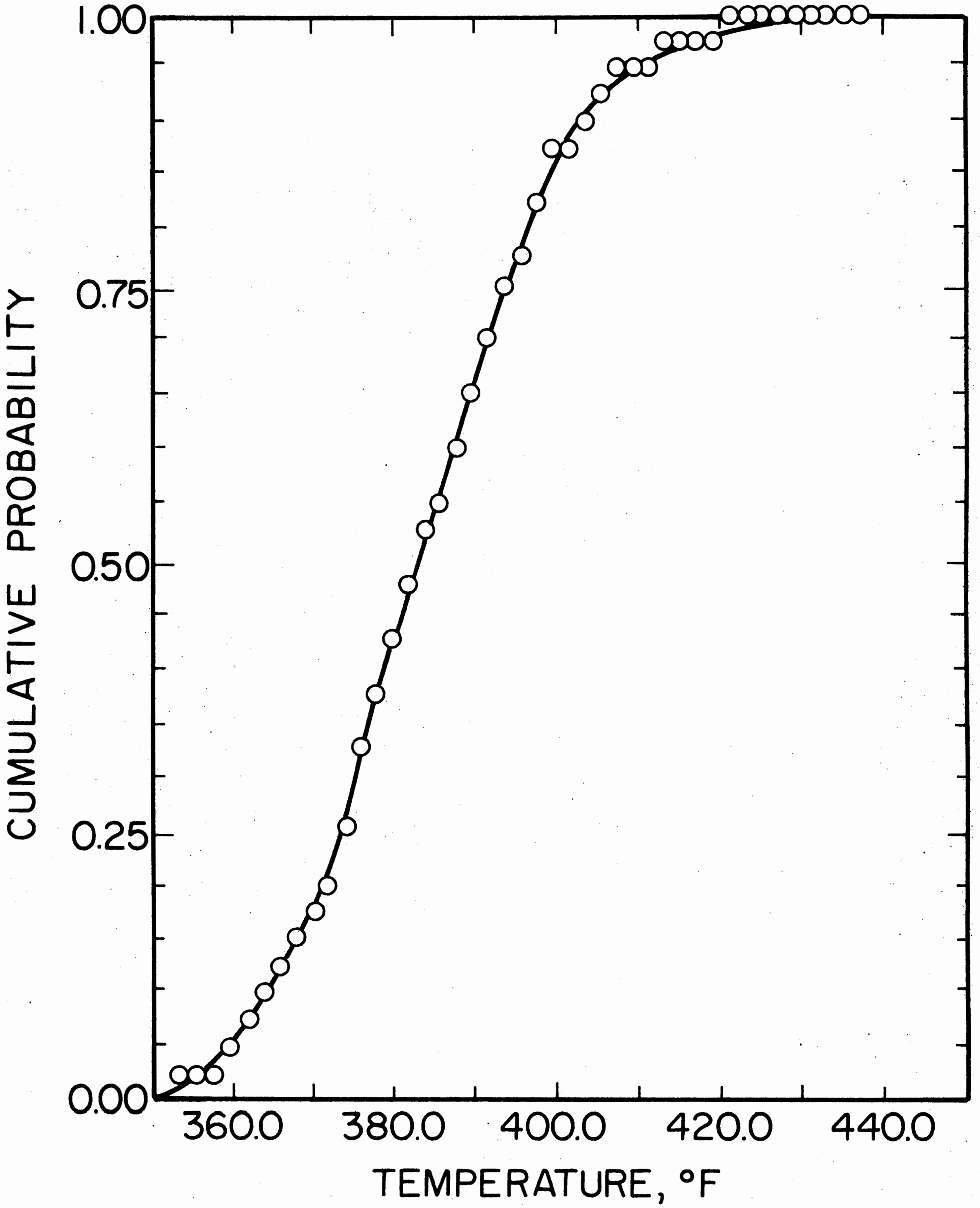


Figure 24. Effluent Stream Number 43; Temperature Cumulative Probability Curve for the Case of 5% and 10% Coefficients of Variation

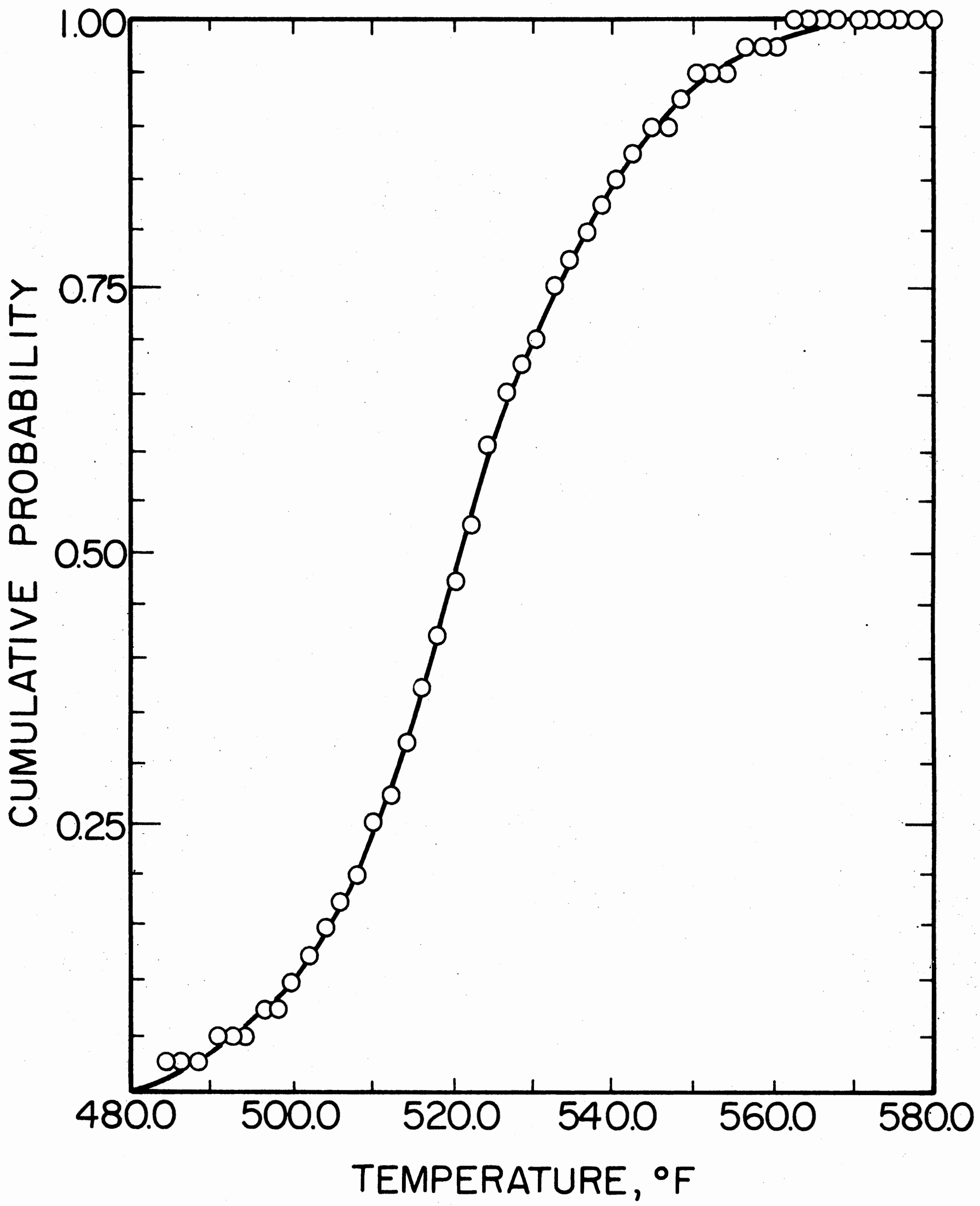


Figure 25. Effluent Stream Number 81; Temperature Cumulative Probability Curve for the Case of 5% and 10% Coefficients of Variation

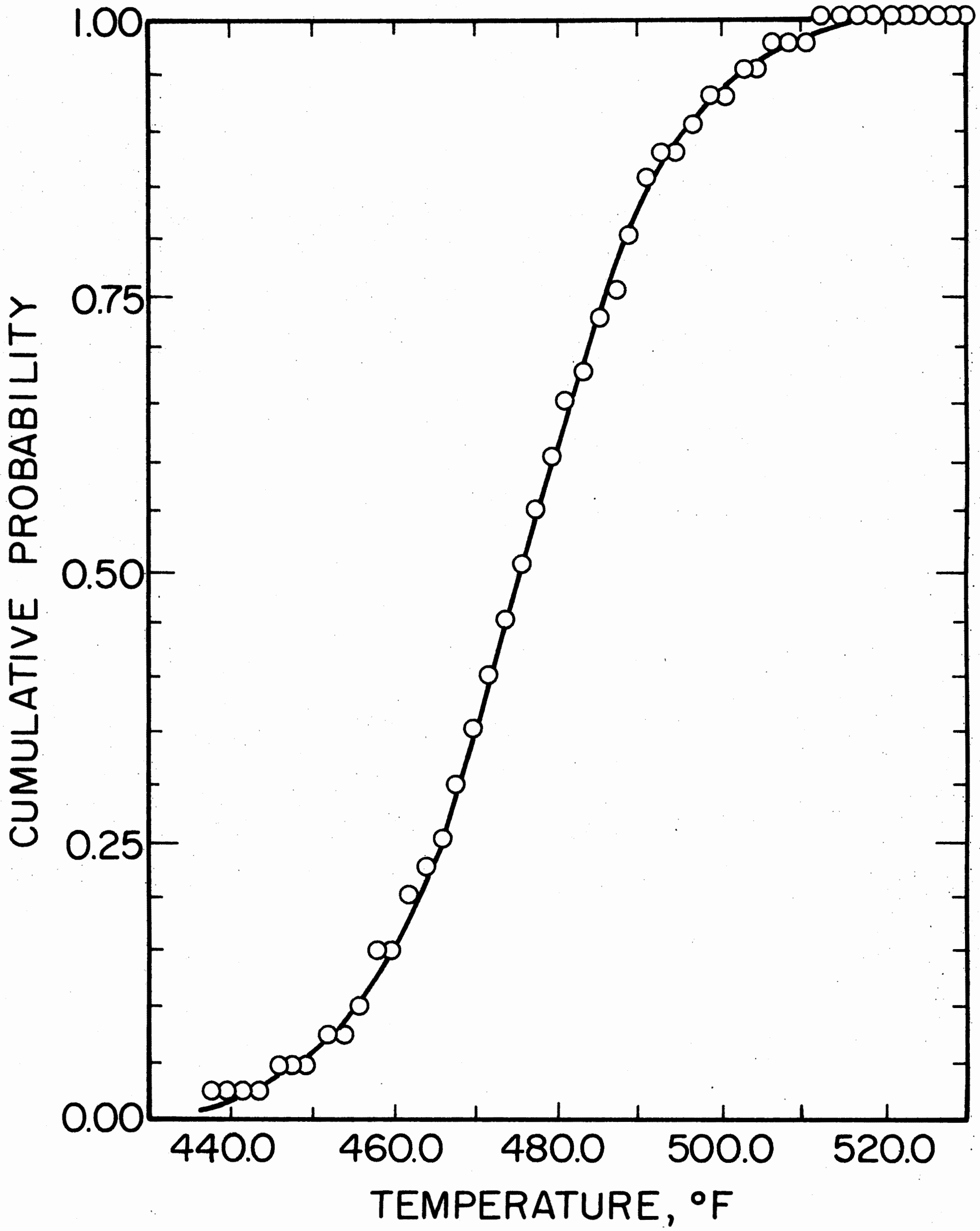


Figure 26. Effluent Stream Number 67; Temperature Cumulative Probability Curve for the Case of 5% and 10% Coefficients of Variation

the population mean in this case the nominal temperature. It is also shown that 500 simulations are sufficient in this case.

Application of Results

Being able to calculate the statistics of any particular outlet stream in the system, an engineer will have some means of predicting the performance of the whole system for a given confidence level. The criteria for the system performance can be specified in more than one way. Some examples of the criteria specification and applications of the results for this problem are as follows:

a. Suppose that the designer wants to make sure that the crude charge effluent stream (number 43) temperature should not be less than $385^{\circ}F$ for a 95% confidence level. To see whether this condition has been satisfied or not, we need to calculate the lower limit for the 95% confidence level using the one tailed test procedure.

   The score Z, for 95% confidence level is read from the table of areas under the standard normal curve given in most statistics books (9) (29), and the standard deviation for the population is estimated by the calculated outlet temperature standard deviation. The lower limit for the temperature is then calculated from the equation

$$T = \overline{T} - Zs$$

   where $\overline{T}$ is the average temperature computed for the sample.

   For the 1% and 5% case, the calculated lower limit for a 95% confidence level was $375.24^{\circ}F$, and for the 5%-10% case, the results was 358.93°F. It is obvious that the system will not perform adequately in each case and that some additional surface is needed.

b. Another insight into the performance of the system can be gained by calculating the interval limits of the temperature for the same stream for a confidence level of 95%. After calculation, it was found that for 95% confidence level the expected temperature of stream 43 will lie in the interval 373.39-396.44°F for the first case and 355.12-414.99°F for the second case. The flash tower calculations are greatly affected by the crude feed temperature and it is important to know range of the expected value. The probability of getting a certain temperature or lower can be also read from the cumulative probability curve supplied by the computer program as a standard output when requested for each outlet stream. Figure 24 shows the probability of obtaining a certain temperature or less for stream number 43.

Additional surface area needed for the whole system can be calculated from the statistics of individual heat exchangers areas. For the case where the designer wants to be 95% sure that the outlet temperature for the crude is 385°F or higher each heat exchanger in the system involving the crude charge should be increased according to the equation

$$A' = \overline{A} + 1.645\ s_A$$

where

A' = new surface area

$\bar{A}$ = average surface area for the heat exchanger calculated

s_A = standard deviation for the heat exchanger area.

The average surface area and standard deviation for each heat exchanger are read from Tables VI and VII for the first and second case respectively.

CHAPTER V

COMPARISONS AND DISCUSSION OF RESULTS

Two procedures have been reported in the literature, each employing statistical methods in the sizing of heat exchangers. The methods are those of Buckley (8) and Berryman and Himmelblau (6) discussed earlier. Buckley provided the following example:

Assume that a countercurrent heat exchanger is to be designed to heat 25,000 lb/hr of an organic liquid (fluid 1) from 100 to 175^{o}F. The specific heat of this fluid has an average of 0.9 Btu/lb^{o}F and a standard deviation of 0.05 Btu/lb^{o}F. The hotter fluid (fluid 2) is another organic liquid with a precise specific heat of 0.86 Btu/lb^{o}F, which is to be cooled from 200 to 180^{o}F. The overall heat transfer coefficient U had been determined to have an ensemble mean of 55 Btu/hrft^{2o}F and a standard deviation of 5 Btu/hrft^{2o}F. It is also stipulated that the designer wants to be 95% confident that the heat exchanger will be adequate.

Buckley solved the problem employing the design equation

$$Q = UA(LMTD) \qquad (5\text{-}1)$$

and calculated the deterministic area to be 650 ft^2. This area is based on the average values for C_{p_1} and U. The uncertainty in the area due to the uncertainties in C_{p_1} and U was then calculated by

Buckley to be 69 ft^2. This is the same as the standard deviation for the area. The final area needed for an upper 95% confidence level was then calculated to be 764 ft^2. The ratio of the stochastic area to the deterministic area was 1.175. This ratio is called the over-design factor.

The same problem has been solved using the procedures proposed in this study and equation (5-1). For 200 simulations where the values for C_{p_1} and U were generated randomly for each simulation, the calculated mean and standard deviation for the area were 654.16 and 71.39 ft^2 respectively. The total area for a 95% confidence level was then calculated to be equal to 771.59 ft^2 and the over design factor was 1.187. Although the difference between the over design factors is not very significant the present method is a better estimate of the actual stochastic process. The recommended method allows for heat balance between the two fluids, whereas Buckley's method does not. When the heat transfer rate increases in the tube side due to an increase in the specific heat C_{p_1}, the shell side outlet temperature will be reduced accordingly since all other variables except U are assumed to be constant. A change in any end temperature will produce a change in LMTD which Buckley's method doesn't consider.

Another example is the one provided by Berryman and Himmelblau. It is assumed that 10 gallons per minute of water is to be cooled in a concentric tube 50 ft long by 10 gallons per minute of brine. The flow is countercurrent and the brine inlet temperature is 470^oR. The uncertainties in the variables and parameters are represented by the coefficient of variation for each. For the inlet temperatures the coefficient of variation is 0.01 and for the flow rates and heat transfer coefficients it is 0.05. For a 99 percent confidence level, what is the length of the pipe if the brine outlet temperature is to be $487^{o}R$ or more? Table IX shows the physical properties given for the fluids and heat exchanger tubes.

The authors approached the problem in a similar way as has been suggested in this study in regard to the use of Monte Carlo method to introduce the random variables in the heat exchanger model equations. The difference is in the choice of the model equation used. Berryman and Himmelblau used the two coupled differential equations resulted from an energy balance on the fluids and tubes

$$\frac{dT}{d\ell} = \frac{1}{(\rho v C_p V)_o} \; \frac{h_o h_i \frac{A_i}{A_o}}{(h_o + h_i \frac{A_i}{A_o})} \; (t-T) \qquad (5\text{-}2)$$

$$\frac{dt}{d\ell} = \frac{1}{(\rho v C_p V)_i} \; \frac{h_o h_i \frac{A_i}{A_o}}{(h_o + h_i \frac{A_i}{A_o})} \; (T-t) \qquad (5\text{-}3)$$

with boundary conditions:

$$t\ (\ell=0) = t_1$$

$$T\ (\ell=0) = T_2$$

The subscripts i and o refer to the inner and outer side of the tube respectively.

TABLE IX

PHYSICAL PROPERTIES OF THE FLUIDS AND THE EXCHANGER TUBES OF EXAMPLE 2

	Inner Pipe Properties		
Weight/Length	$(eV)_w$	2.272	lb/ft
Wall Area	A_i	0.36125	ft^2/ft
	A_o	0.43458	ft^2/ft
Specific heat	C_{p_w}	0.113	Btu/lb^oF
	Pipe Volume Per Length		
Inner tube	V_i	0.01038	ft^3/ft
Annulus	V_o	0.01822	ft^3/ft
	Brine		
Density	ρ_i	77.044	lb/ft^3
Specific heat	C_{p_i}	0.68	Btu/lb^oF
Flow rate	v_i	10.0	gal/min
	Water		
Density	ρ_o	62.46	lb/ft^3
Specific heat	C_{p_o}	1.0	Btu/lb^oF
Flow rate	v_o	10.0	gal/min
	Heat Transfer Coefficients		
Brine to inner pipe	h_i	265.0	$Btu/hrft^{2o}F$
Water to inner pipe	h_o	178.0	$Btu/hrft^{2o}F$

They integrated those equations in one direction starting from one end of the heat exchanger where the boundary conditions are specified to avoid the trial and error procedure. When the integration was carried out, the calculated overdesign factor for the concentric pipe was found to be 1.60. The heat exchanger was then simulated according to the present method where the deterministic solution of the differential equations, the design equation, was employed. The calculated overdesign factor for this procedure was found to be 1.738. The extra area required here is mainly due to the different boundary conditions used in the two models. When the design equation is used the inlet temperature of the water is allowed to fluctuate instead of the outlet temperature as has been used by Berryman and Himmelblau. This adds extra uncertainty since the inlet temperature of the hot fluid, namely water, is always greater than the outlet temperature. When the brine inlet temperature and the water outlet temperature were allowed to vary the calculated overdesign factor using the present methods was 1.58. It is believed that any approximation built into the design equation is outweighed by the relative ease of its use especially when there is more than one tube pass in the heat exchanger.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

A method for estimation of the performance of systems of heat exchangers has been suggested. This method includes uncertainties in input data and uses a general computer program developed for this purpose. Upon the previous discussion of the method and the tests made the following conclusions are drawn:

1. The recommended method predicts the performance of heat exchanger systems for as many as 98 heat exchangers in a system with a reasonable accuracy.

2. When the method was compared with others in the literature it was found that the suggested method yielded values for the over-design factor and the outlet stream temperatures statistics not far from both methods.

3. Use of the heat exchanger design equation instead of integrating the governing differential equations (Equations 5-2, 5-3) through the heat exchanger gives similar values for the overdesign factors when the boundary conditions considered are the same.

4. The precision of predicting the performance of the system is as good as the assumptions put into the procedures. This is evident in the case of the coefficient of variation chosen for each variable and how close it is to the actual variation, and in the calculated sample mean and standard deviation for the output and how they

resemble the mean and standard deviation for the whole population. The latter part is a function of number of simulations carried out.

5. The coefficient of variation for the input variables and parameters should be chosen wisely so as to reflect the actual process. Too large a coefficient of variation might not produce the proper standard deviations for the outlet streams and design parameters.

Extra work needs to be done to facilitate the understanding of the various relationships involved in the calculation of heat exchangers performance. The following recommendations are suggested for further work:

1. Modification of the program to include multiple shells which are not in pure series or parallel arrangement but a mixture of both. Such an arrangement requires trial and error in the calculation of outlet temperatures for each shell and has not been accounted for.

2. Expansion of the program to include other types of heat exchangers.

3. Study the effect of violating some of the assumptions made in the deviation of the design equation for heat exchangers, such as the assumption of constant overall coefficient, on the performance of the system.

SELECTED BIBLIOGRAPHY

1. Alfa-Laval, Thermal Handbook, Västerås, Sweden: Alfa-Laval, (1969).

2. Andersen, L. B., "Probability Theory Provides Simple Statistical Models," Chem. Engr., 125-132, (Nov. 26, 1962).

3. Bell, Kenneth J., "Exchanger Design-Based on the Delaware Research Program," Petro. Chem. Eng. 32, No. 11, C-26, (October, 1960).

4. Bell, Kenneth J., "Process Heat Transfer," (Unpub. Class Notes, 1973).

5. Berryman, J. E. and D. M. Himmelblau, "Effect of Stachastic Inputs and Parameters on Process Analysis and Design," Ind. Eng. Chem. Process Des. Dev., 10, No. 4, 441-449, (1971).

6. Berryman, J. E. and D. M. Himmelblau, "Influence of Stochastic Inputs and Parameters on Heat Exchanger Design," Ind. Eng. Chem. Process Des. Dev. 12, No. 2, 165-171, (1973).

7. Bowman, R. A., A. C. Mueller and W. M. Nagle, "Mean Temperature Difference in Design," Trans ASME, 62, 283-294, (1940).

8. Buckley, Page S., "Sizing Process Equipment by Statistical Methods," Chem. Engr., 57, No. 9, 112-114, (1950).

9. Burlington, R. S. and D. C. May, Handbook of Probability and Statistics with Tables, 2nd Ed., New York: McGraw-Hill, (1969).

10. Cary, J. R., "Fast, Convenient Approach to Sizing Heat Exchangers," Chem. Engr., 66, No. 10, 169, (1959).

11. Crowe, C. M., et al., Chemical Plant Simulation, An Introduction to Computer-Aided Steady-State Process Analysis, Englewood Cliffs, N. J.: Prentice-Hall, Inc., (1971).

12. Eckert, E. R. G. and Robert M. Drake, Jr., Analysis of Heat and Mass Transfer, New York: McGraw-Hill Book Co., (1972).

13. Franks, Roger G. E., Modeling and Simulation in Chemical Engineering, New York: Wiley-Interscience, (1972).

14. Hamming, R. W., Numerical Methods for Scientists and Engineers, New York: McGraw-Hill Book Co., (1962).

15. Holland, R. A., F. A. Watson and J. K. Wilkinson, "Statistical Techniques Improve Decision-Making," Chem. Engr. 61-66, (Dec. 24, 1973).

16. Holland, F. A., F. A. Watson and J. K. Wilkinson, "Probability Techniques for Estimates of Profitability," Chem. Engr., 105-110, (Jan. 7, 1974).

17. Holland, R. A., F. A. Watson and J. K. Wilkinson, "Estimation of Profitability When Uncertainties Exist," Chem. Engr., 73-79, (Feb. 4, 1974).

18. Huag, F. and R. Elshout, "Optimizing the Heat Recovery of Crude Units," Chem. Engr. Prog., 68-74, (July, 1976).

19. IBM Manual C20-8011, Random Number Generation and Testing.

20. Kays, W. M. and A. L. London, Compact Heat Exchangers, 2nd Ed. New York: McGraw-Hill Book Co., (1964).

21. Kern, Donald Q., Process Heat Transfer, New York: McGraw-Hill Book Co., (1950).

22. Kern, Donald Q. and Allen D. Kraus, Extended Surface Heat Transfer, New York: McGraw-Hill Book Co., (1972).

23. Knudsen, J. G. and D. Katz, Fluid Dynamics and Heat Transfer, New York: McGraw-Hill Book Co., (1958).

24. McAdams, William H., Heat Transmission, New York: McGraw-Hill Book Co. (1954).

25. Parker, Jerald D., James H. Boggs and Edward F. Blick, Introduction to Fluid Mechanics and Heat Transfer, Reading Mass, (1970).

26. Rohsenow, Warren M., James P. Hartnett, Handbook of Heat Transfer, New York: McGraw-Hill Book Co., (1973).

27. Shreider, Yu. A., The Monte Carlo Method, New York: Pergamon Press, (1966).

28. Small, W. M. Personal Communication, Stillwater, Oklahoma, (May, 1976).

29. Snedecor, George W. and William G. Cochran, Statistical Methods, 6th Ed., Ames, Iowa: Iowa State University Press, (1967).

APPENDIX A

RESULTS OF THE TEMPERATURE CALCULATION OF THE CRUDE PREHEAT TRAIN FOR THE CASE OF 5% AND 10% COEFFICIENTS OF VARIATION

STREAM DIVIDER

ELEMENT NUMBER ** 3

NUMBER OF FEED STREAMS** 1 NUMBER OF PRODUCT STREAMS** 2

	FEED	PRODUCT			
STREAM NUMBER	16	17	23	0	0
FLOW RATE LB/HR	712670.00	356335.00	356335.00	0.0	0.0
TEMPERATURE,DEG F	94.00	94.00	94.00	0.0	0.0
HEAT CAPACITY,BTU/LB F	0.49300	0.49300	0.49300	0.0	0.0
FLOW RATE STD,LB/HR	35633.50	17816.75	17816.75	0.0	0.0
TEMPERATURE STD,DEG F	0.94	0.94	0.94	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0	0.0

STREAM DIVIDER

ELEMENT NUMBER** 4

NUMBER OF FEED STREAMS** 1 NUMBER OF PRODUCT STREAMS** 2

	FEED	PRODUCT			
STREAM NUMBER	10	11	13	0	0
FLOW RATE LB/HR	10380.00	5190.00	5190.00	0.0	0.0
TEMPERATURE,DEG F	306.00	306.00	306.00	0.0	0.0
HEAT CAPACITY,BTU/LB F	16.43300	16.43300	16.43300	0.0	0.0
FLOW RATE STD,LB/HR	519.00	259.50	259.50	0.0	0.0
TEMPERATURE STD,DEG F	3.06	3.06	3.06	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0	0.0

STREAM DIVIDER

ELEMENT NUMBER ** 5

NUMBER OF FEED STREAMS** 1 NUMBER OF PRODUCT STREAMS** 2

	FEED	PRODUCT			
STREAM NUMBER	1	2	5	0	0
FLOW RATE LB/HR	171310.00	85655.00	85655.00	0.0	0.0
TEMPERATURE,DEG F	284.00	284.00	284.00	0.0	0.0
HEAT CAPACITY,BTU/LB F	2.94300	2.94300	2.94300	0.0	0.0
FLOW RATE STD.LB/HR	8565.50	4282.75	4282.75	0.0	0.0
TEMPERATURE STD,DEG F	2.84	2.84	2.84	0.0	0.0
HEAT CAPACITY STD.BTU/LB F	0.0	0.0	0.0	0.0	0.0

HEAT EXCHANGER

ELEMENT NUMBER** 6

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	17	11	18	12
FLOW RATE,LB/HR	356335.00	5190.00	356335.00	5190.00
TEMPERATURE,DEG F	94.00	306.00	159.98	170.10
HEAT CAPACITY,BTU/LB F	0.49300	16.43300	0.49300	16.43300
FLOW RATE STD,LB/HR	17816.75	259.50	0.0	0.0
TEMPERATURE STD,DEG F	0.94	3.06	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	450.00000	22.50000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	295.00000	14.75000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00375	0.00019
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00160	0.00008
OVERALL COEFF.,BTU/SQR FT HR DEG F	77.12622	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.1159E+06 BTU/HR

AREA REQUIRED- 1650.00 SQR FT

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN *** OUTPUT LISTING ***

HEAT EXCHANGER

ELEMENT NUMBER** 7

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	23	13	29	14
FLOW RATE,LB/HR	356335.00	5190.00	356335.00	5190.00
TEMPERATURE,DEG F	94.00	306.00	159.98	170.10
HEAT CAPACITY,BTU/LB F	0.49300	16.43300	0.49300	16.43300
FLOW RATE STD,LB/HR	17816.75	259.50	0.0	0.0
TEMPERATURE STD,DEG F	0.94	3.06	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	450.00000	22.50000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	295.00000	14.75000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00375	0.00019
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00160	0.00008
OVERALL COEFF.,BTU/SQR FT HR DEG F	77.12622	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20460	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.1159E+08 BTU/HR

AREA REQUIRED 1650.00 SQR FT

STREAM DIVIDER

ELEMENT NUMBER** 9

NUMBER OF FEED STREAMS** 1 NUMBER OF PRODUCT STREAMS** 2

	FEED	PRODUCT			
STREAM NUMBER	18	19	21	0	0
FLOW RATE LB/HR	356335.00	178167.50	178167.50	0.0	0.0
TEMPERATURE,DEG F	159.98	159.98	159.98	0.0	0.0
HEAT CAPACITY,BTU/LB F	0.49300	0.49300	0.49300	0.0	0.0
FLOW RATE STD,LB/HR	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD,DEG F	0.0	0.0	0.0	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0	0.0

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN *** OUTPUT LISTING ***

HEAT EXCHANGER

ELEMENT NUMBER** 10

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	19	2	20	3
FLOW RATE,LB/HR	178167.50	85655.00	178167.50	85655.00
TEMPERATURE,DEG F	159.98	284.00	253.01	250.99
HEAT CAPACITY,BTU/LB F	0.50200	2.94300	0.50200	2.94300
FLOW RATE STD,LB/HR	0.0	4282.75	0.0	0.0
TEMPERATURE STD,DEG F	0.0	2.84	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	460.00000	23.00000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	150.00000	7.50000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00423	0.00021
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00300	0.00015
OVERALL COEFF.,BTU/SQR FT HR DEG F	54.96185	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 2

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.8320E+07 BTU/HR

AREA REQUIRED 1420.00 SQR FT

HEAT EXCHANGER

ELEMENT NUMBER** 11

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	21	3	22	4
FLOW RATE,LB/HR	178167.50	85655.00	178167.50	85655.00
TEMPERATURE,DEG F	159.98	250.99	203.04	233.97
HEAT CAPACITY,BTU/LB F	0.50200	2.64120	0.50200	2.64120
FLOW RATE STD,LB/HR	0.0	0.0	0.0	0.0
TEMPERATURE STD,DEG F	0.0	0.0	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	460.00000	23.00000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	140.00000	7.00000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00450	0.00023
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00320	0.00016
OVERALL COEFF.,BTU/SQR FT HR DEG F	52.04057	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.3652E+07 BTU/HR

AREA REQUIRED 1278.00 SQR FT

STREAM DIVIDER

ELEMENT NUMBER** 12

NUMBER OF FEED STREAMS** 1 NUMBER OF PRODUCT STREAMS** 2

	FEED	PRODUCT			
STREAM NUMBER	29	24	26	0	0
FLOW RATE LB/HR	356335.00	178167.50	178167.50	0.0	0.0
TEMPERATURE,DEG F	159.98	159.98	159.98	0.0	0.0
HEAT CAPACITY,BTU/LB F	0.49300	0.49300	0.49300	0.0	0.0
FLOW RATE STD.LB/HR	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD.DEG F	0.0	0.0	0.0	0.0	0.0
HEAT CAPACITY STD.BTU/LB F	0.0	0.0	0.0	0.0	0.0

HEAT EXCHANGER

ELEMENT NUMBER** 13

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	24	5	25	6
FLOW RATE,LB/HR	178167.50	85655.00	178167.50	85655.00
TEMPERATURE,DEG F	159.98	284.00	253.01	250.99
HEAT CAPACITY,BTU/LB F	0.50200	2.94300	0.50200	2.94300
FLOW RATE STD,LB/HR	0.0	4282.75	0.0	0.0
TEMPERATURE STD,DEG F	0.0	2.84	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	460.00000	23.00000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	150.00000	7.50000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00423	0.00021
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00300	0.00015
OVERALL COEFF.,BTU/SQR FT HR DEG F	54.96185	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 2

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.8320E+07 BTU/HR

AREA REQUIRED 1420.00 SQR FT

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN *** OUTPUT LISTING ***

HEAT EXCHANGER

ELEMENT NUMBER** 14

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	26	6	27	7
FLOW RATE,LB/HR	178167.50	85655.00	178167.50	85655.00
TEMPERATURE,DEG F	159.98	250.99	203.04	233.97
HEAT CAPACITY,BTU/LB F	0.50200	2.64120	0.50200	2.64120
FLOW RATE STD,LB/HR	0.0	0.0	0.0	0.0
TEMPERATURE STD,DEG F	0.0	0.0	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	460.00000	23.00000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	140.00000	7.00000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00450	0.00023
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00320	0.00016
OVERALL COEFF.,BTU/SQR FT HR DEG F	52.04057	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20430	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.3852E+07 BTU/HR

AREA REQUIRED 1278.00 SQR FT

STREAM ADDER

ELEMENT NUMBER** 8

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 1

	FEED				PRODUCT
STREAM NUMBER	12	14	0	0	15
FLOW RATE LB/HR	5190.00	5190.00	0.0	0.0	10380.00
TEMPERATURE DEG F	170.10	170.10	0.0	0.0	170.10
HEAT CAPACITY BTU/LB F	16.43300	16.43300	0.0	0.0	16.43298
FLOW RATE STD LB/HR	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD,DEG F	0.0	0.0	0.0	0.0	0.0
HEAT CAPACITY STD BTU/LB F	0.0	0.0	0.0	0.0	0.0

STREAM ADDER

ELEMENT NUMBER** 15

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 1

	FEED				PRODUCT
STREAM NUMBER	4	7	0	0	8
FLOW RATE LB/HR	85655.00	85655.00	0.0	0.0	171310.00
TEMPERATURE DEG F	233.97	233.97	0.0	0.0	233.97
HEAT CAPACITY BTU/LB F	2.64120	2.64120	0.0	0.0	2.64120
FLOW RATE STD LB/HR	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD,DEG F	0.0	0.0	0.0	0.0	0.0
HEAT CAPACITY STD BTU/LB F	0.0	0.0	0.0	0.0	0.0

STREAM ADDER

ELEMENT NUMBER** 16

NUMBER OF FEED STREAMS** 4 NUMBER OF PRODUCT STREAMS** 1

	FEED				PRODUCT
STREAM NUMBER	20	22	25	27	28
FLOW RATE LB/HR	178167.50	178167.50	178167.50	178167.50	712670.00
TEMPERATURE DEG F	253.01	203.04	253.01	203.04	228.02
HEAT CAPACITY BTU/LB F	0.50200	0.50200	0.50200	0.50200	0.50200
FLOW RATE STD LB/HR	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD.DEG F	0.0	0.0	0.0	0.0	0.0
HEAT CAPACITY STD BTU/LB F	0.0	0.0	0.0	0.0	0.0

HEAT EXCHANGER

ELEMENT NUMBER** 29

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	60	70	61	71
FLOW RATE,LB/HR	634300.00	91216.00	634300.00	91216.00
TEMPERATURE,DEG F	367.00	579.00	394.14	410.23
HEAT CAPACITY,BTU/LB F	0.62600	0.70000	0.62600	0.70000
FLOW RATE STD,LB/HR	31715.00	4560.80	0.0	0.0
TEMPERATURE STD,DEG F	3.67	5.79	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	385.00000	19.25000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	290.00000	14.50000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00246	0.00012
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00150	0.00008
OVERALL COEFF.,BTU/SQR FT HR DEG F	85.07179	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT - PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.1078E+08 BTU/HR

AREA REQUIRED 1440.00 SQR FT

STREAM DIVIDER

ELEMENT NUMBER ** 30

NUMBER OF FEED STREAMS ** 1 NUMBER OF PRODUCT STREAMS ** 2

	FEED	PRODUCT			
STREAM NUMBER	61	62	63	0	0
FLOW RATE LB/HR	634300.00	317150.00	317150.00	0.0	0.0
TEMPERATURE,DEG F	394.14	394.14	394.14	0.0	0.0
HEAT CAPACITY,BTU/LB F	0.62600	0.62600	0.62600	0.0	0.0
FLOW RATE STD.LB/HR	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD.DEG F	0.0	0.0	0.0	0.0	0.0
HEAT CAPACITY STD.BTU/LB F	0.0	0.0	0.0	0.0	0.0

HEAT EXCHANGER

ELEMENT NUMBER** 32

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	62	75	65	76
FLOW RATE,LB/HR	317150.00	144039.00	317150.00	144039.00
TEMPERATURE,DEG F	394.14	631.00	460.08	550.18
HEAT CAPACITY,BTU/LB F	0.66800	1.20000	0.66800	1.20000
FLOW RATE STD,LB/HR	0.0	7201.95	0.0	0.0
TEMPERATURE STD,DEG F	0.0	6.31	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	200.00000	10.00000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	142.89999	7.15000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00270	0.00013
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00100	0.00005
OVERALL COEFF.,BTU/SQR FT HR DEG F	54.99800	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.1397E+08 BTU/HR

AREA REQUIRED 1610.00 SQR FT

HEAT EXCHANGER

ELEMENT NUMBER ** 31

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS ** 2

	FEED		PRODUCT	
STREAM NUMBER	63	76	64	77
FLOW RATE,LB/HR	317150.00	144039.00	317150.00	144039.00
TEMPERATURE,DEG F	394.14	550.18	459.71	469.30
HEAT CAPACITY,BTU/LB F	0.66800	1.20000	0.66800	1.20000
FLOW RATE STD,LB/HR	0.0	0.0	0.0	0.0
TEMPERATURE STD,DEG F	0.0	0.0	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	200.00000	10.00000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	181.30000	9.10000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00270	0.00013
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00100	0.00005
OVERALL COEFF.,BTU/SQR FT HR DEG F	59.93361	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20430	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.1389E+08 BTU/HR

AREA REQUIRED 3272.00 SQR FT

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN *** OUTPUT LISTING ***

STREAM ADDER

ELEMENT NUMBER** 33

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 1

	FEED				PRODUCT
STREAM NUMBER	64	65	0	0	66
FLOW RATE LB/HR	317150.00	317150.00	0.0	0.0	634300.00
TEMPERATURE DEG F	459.71	460.08	0.0	0.0	459.90
HEAT CAPACITY BTU/LB F	0.66800	0.66800	0.0	0.0	0.66800
FLOW RATE STD LB/HR	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD.DEG F	0.0	0.0	0.0	0.0	0.0
HEAT CAPACITY STD BTU/LB F	0.0	0.0	0.0	0.0	0.0

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN *** OUTPUT LISTING ***

HEAT EXCHANGER

ELEMENT NUMBER** 34

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	66	80	67	81
FLOW RATE,LB/HR	634300.00	86166.00	634300.00	86166.00
TEMPERATURE,DEG F	459.90	642.00	476.92	521.81
HEAT CAPACITY,BTU/LB F	0.70000	0.73000	0.70000	0.73000
FLOW RATE STD,LB/HR	0.0	4308.30	0.0	0.0
TEMPERATURE STD,DEG F	0.0	6.42	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	327.00000	16.35001
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	380.00000	19.00000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00200	0.00010
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00166	0.00008
OVERALL COEFF.,BTU/SQR FT HR DEG F	90.09842	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.7560E+07 BTU/HR

AREA REQUIRED 825.00 SQR FT

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN   *** OUTPUT LISTING ***

HEAT EXCHANGER

ELEMENT NUMBER** 17

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	30	71	31	72
FLOW RATE,LB/HR	712670.00	91216.00	712670.00	91216.00
TEMPERATURE,DEG F	226.00	410.23	249.69	254.31
HEAT CAPACITY,BTU/LB F	0.55000	0.65300	0.55000	0.65300
FLOW RATE STD,LB/HR	35633.50	0.0	0.0	0.0
TEMPERATURE STD,DEG F	2.26	0.0	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	160.00000	8.00000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	120.00000	6.00000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00780	0.00039
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00550	0.00028
OVERALL COEFF.,BTU/SQR FT HR DEG F	31.11847	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT   PAR-CNTR

NUMBER OF SHELL-PASSES   2

ISOTHERMAL STREAM FLOW RATE   0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0   BTU/LB

HEAT TRANSFERED 0.9287E+07 BTU/HR

AREA REQUIRED 2015.00 SQR FT

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN *** OUTPUT LISTING ***

STREAM DIVIDER

ELEMENT NUMBER** 18

NUMBER OF FEED STREAMS** 1 NUMBER OF PRODUCT STREAMS** 2

	FEED	PRODUCT			
STREAM NUMBER	31	32	34	0	0
FLOW RATE LB/HR	712670.00	356335.00	356335.00	0.0	0.0
TEMPERATURE,DEG F	249.69	249.69	249.69	0.0	0.0
HEAT CAPACITY,BTU/LB F	0.55000	0.55000	0.55000	0.0	0.0
FLOW RATE STD,LB/HR	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD,DEG F	0.0	0.0	0.0	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0	0.0

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN *** OUTPUT LISTING ***

HEAT EXCHANGER

ELEMENT NUMBER** 20

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	34	45	35	46
FLOW RATE,LB/HR	356335.00	69062.00	356335.00	69062.00
TEMPERATURE,DEG F	249.69	413.00	274.73	300.85
HEAT CAPACITY,BTU/LB F	0.58000	0.66800	0.58000	0.66800
FLOW RATE STD,LB/HR	0.0	3453.10	0.0	0.0
TEMPERATURE STD,DEG F	0.0	4.13	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	222.20000	11.11000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	192.30000	9.62000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00300	0.00015
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00160	0.00008
OVERALL COEFF.,BTU/SQR FT HR DEG F	59.77394	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.5174E+07 BTU/HR

AREA REQUIRED 1060.00 SQR FT

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN *** OUTPUT LISTING ***

HEAT EXCHANGER

ELEMENT NUMBER ** 19

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	32	46	33	47
FLOW RATE,LB/HR	356335.00	69062.00	356335.00	69062.00
TEMPERATURE,DEG F	249.69	300.35	256.71	266.79
HEAT CAPACITY,BTU/LB F	0.56000	0.59500	0.56000	0.59500
FLOW RATE STD,LB/HR	0.0	0.0	0.0	0.0
TEMPERATURE STD,DEG F	0.0	0.0	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	200.00000	10.00000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	154.00000	7.70000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00400	0.00020
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00300	0.00015
OVERALL COEFF.,BTU/SQR FT HR DEG F	46.86057	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.1400E+07 BTU/HR

AREA REQUIRED 1107.00 SQR FT

STREAM ADDER

ELEMENT NUMBER** 21

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 1

	FEED				PRODUCT
STREAM NUMBER	33	35	0	0	36
FLOW RATE LB/HR	356335.00	356335.00	0.0	0.0	712670.00
TEMPERATURE DEG F	256.71	274.73	0.0	0.0	265.72
HEAT CAPACITY BTU/LB F	0.56000	0.58000	0.0	0.0	0.57000
FLOW RATE STD LB/HR	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD,DEG F	0.0	0.0	0.0	0.0	0.0
HEAT CAPACITY STD BTU/LB F	0.0	0.0	0.0	0.0	0.0

PROBLEM IDENTIFICATICN***CRUDE PREHEAT TRAIN *** OUTPUT LISTING ***

HEAT EXCHANGER

ELEMENT NUMBER** 22

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	36	77	37	78
FLOW RATE,LB/HR	712670.00	144039.00	712670.00	144039.00
TEMPERATURE,DEG F	265.72	469.80	302.64	308.11
HEAT CAPACITY,BTU/LB F	0.58500	0.66100	0.58500	0.66100
FLOW RATE STD,LB/HR	0.0	0.0	0.0	0.0
TEMPERATURE STD,DEG F	0.0	0.0	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	333.33008	16.67000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	285.69995	14.29000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00250	0.00013
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00163	0.00008
OVERALL COEFF.,BTU/SQR FT HR DEG F	79.98405	0.0
TUBE WALL THERMAL CCNDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLCW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFEREC 0.1540E+08 BTU/HR

AREA REQUIRED 2496.00 SQR FT

STREAM DIVIDER

ELEMENT NUMBER** 23

NUMBER OF FEED STREAMS** 1 NUMBER OF PRODUCT STREAMS** 2

	FEED	PRODUCT			
STREAM NUMBER	37	38	40	0	0
FLOW RATE LB/HR	712670.00	356335.00	356335.00	0.0	0.0
TEMPERATURE,DEG F	302.64	302.64	302.64	0.0	0.0
HEAT CAPACITY,BTU/LB F	0.58500	0.58500	0.58500	0.0	0.0
FLOW RATE STD,LB/HR	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD,DEG F	0.0	0.0	0.0	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0	0.0

HEAT EXCHANGER

ELEMENT NUMBER** 25

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	40	50	41	51
FLOW RATE,LB/HR	356335.00	94220.00	356335.00	94220.00
TEMPERATURE,DEG F	302.64	491.00	339.48	363.78
HEAT CAPACITY,BTU/LB F	0.60000	0.65700	0.60000	0.65700
FLOW RATE STD,LB/HR	0.0	4711.00	0.0	0.0
TEMPERATURE STD,DEG F	0.0	4.91	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	284.00000	14.20000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	196.00000	9.80000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00500	0.00025
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00470	0.00023
OVERALL COEFF.,BTU/SQR FT HR DEG F	47.53691	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20460	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT   PAR-CNTR

NUMBER OF SHELL-PASSES   1

ISOTHERMAL STREAM FLOW RATE   0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0   BTU/LB

HEAT TRANSFERED 0.7875E+07 BTU/HR

AREA REQUIRED   1825.00 SQR FT

HEAT EXCHANGER

ELEMENT NUMBER ** 24

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	38	51	39	52
FLOW RATE, LB/HR	356335.00	94220.00	356335.00	94220.00
TEMPERATURE, DEG F	302.64	363.78	312.20	328.71
HEAT CAPACITY, BTU/LB F	0.59400	0.61200	0.59400	0.61200
FLOW RATE STD, LB/HR	0.0	0.0	0.0	0.0
TEMPERATURE STD, DEG F	0.0	0.0	0.0	0.0
HEAT CAPACITY STD, BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF., BTU/SQR FT HR DEG F	312.50000	15.62500
OUTSIDE COEFF., BTU/SQR FT HR DEG F	357.10010	17.86000
INSIDE FOULING FACTR, SQR FT HR DEGF/BTU	0.00206	0.00010
OUTSIDE FOULING FACTR, SQR FT HR DEG F/BTU	0.00180	0.00009
OVERALL COEFF., BTU/SQR FT HR DEG F	85.72052	0.0
TUBE WALL THERMAL CONDTY, BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.2022E+07 BTU/HR

AREA REQUIRED 659.00 SQR FT

STREAM ADDER

ELEMENT NUMBER** 26

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 1

	FEED				PRODUCT
STREAM NUMBER	39	41	0	0	42
FLOW RATE LB/HR	356335.00	356335.00	0.0	0.0	712670.00
TEMPERATURE DEG F	312.20	339.48	0.0	0.0	325.34
HEAT CAPACITY BTU/LB F	0.59400	0.60000	0.0	0.0	0.59700
FLOW RATE STD LB/HR	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD.DEG F	0.0	0.0	0.0	0.0	0.0
HEAT CAPACITY STD BTU/LB F	0.0	0.0	0.0	0.0	0.0

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN *** OUTPUT LISTING ***

HEAT EXCHANGER

ELEMENT NUMBER** 27

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	42	55	43	56
FLOW RATE,LB/HR	712670.00	361150.00	712670.00	361150.00
TEMPERATURE,DEG F	325.84	509.00	384.92	405.90
HEAT CAPACITY,BTU/LB F	0.56600	0.64000	0.56600	0.64000
FLOW RATE STD,LB/HR	0.0	18057.50	0.0	0.0
TEMPERATURE STD,DEG F	0.0	5.09	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	413.00000	20.64999
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	600.00000	30.00000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00150	0.00008
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00066	0.00003
OVERALL COEFF.,BTU/SQR FT HR DEG F	130.19350	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 2

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.2383E+08 BTU/HR

AREA REQUIRED 935.00 SQR FT

OUTPUT TANK

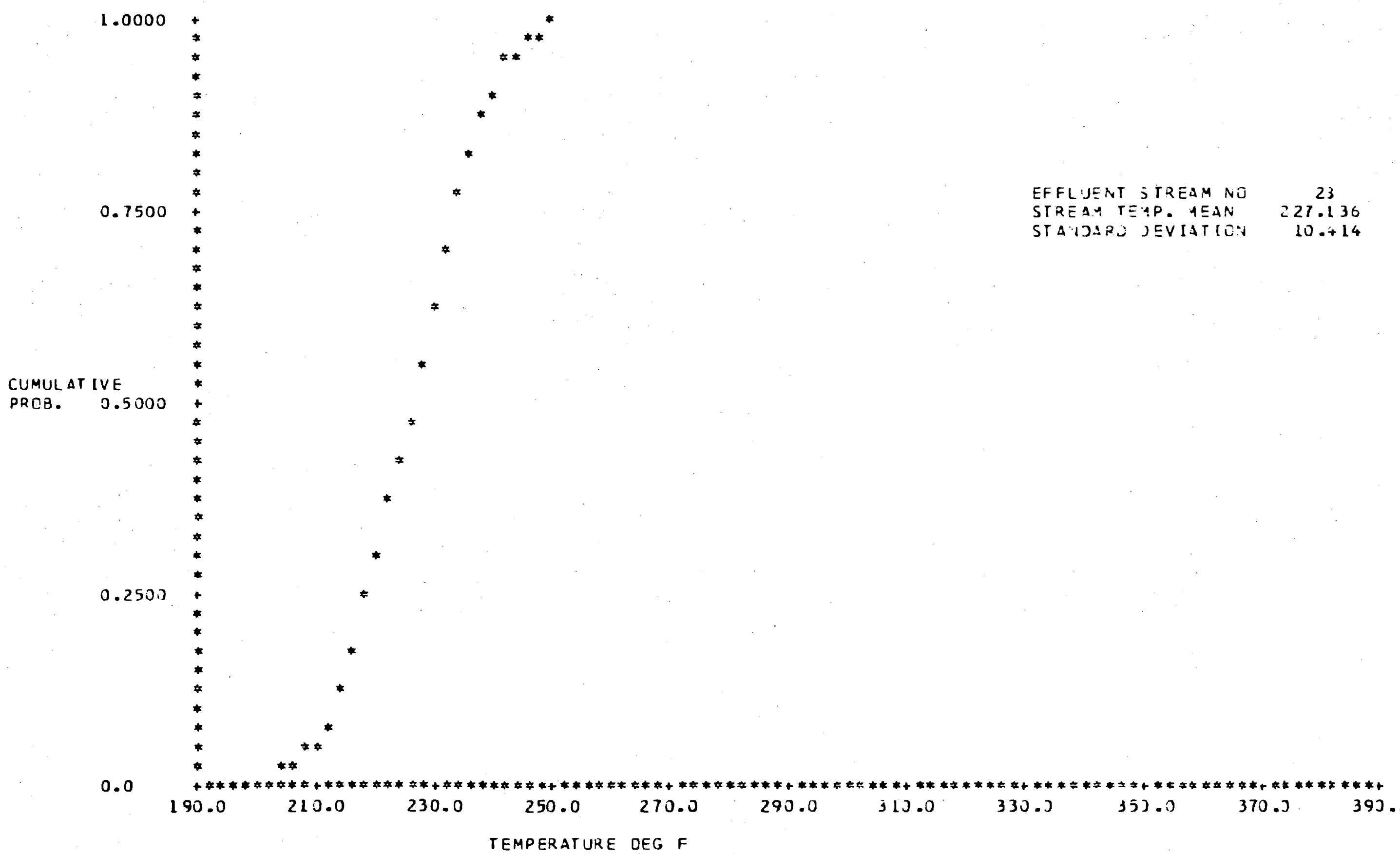
ELEMENT NUMBER** 35

NUMBER OF FEED STREAMS** 11 NUMBER OF PRODUCT STREAMS** 0

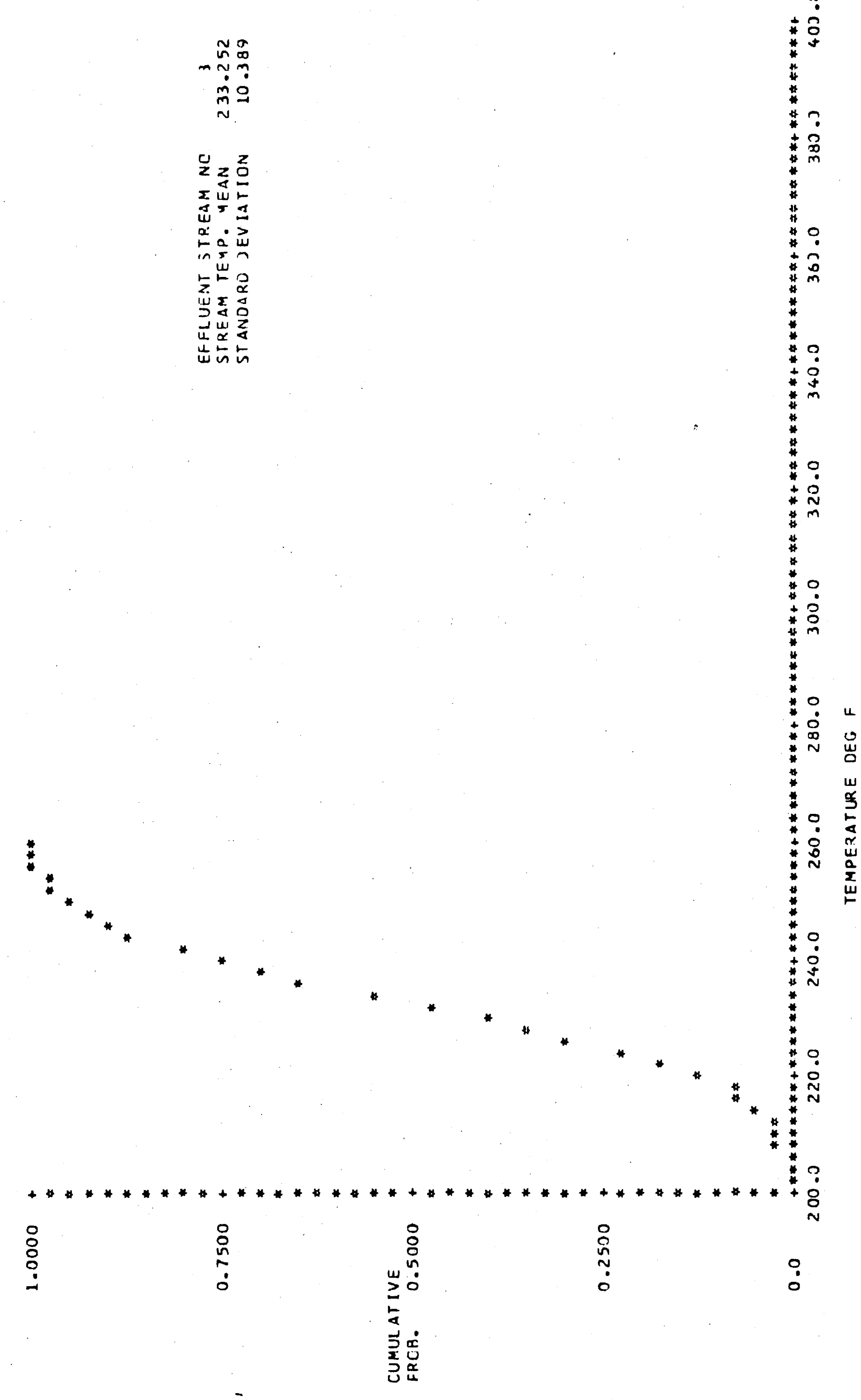
FEED

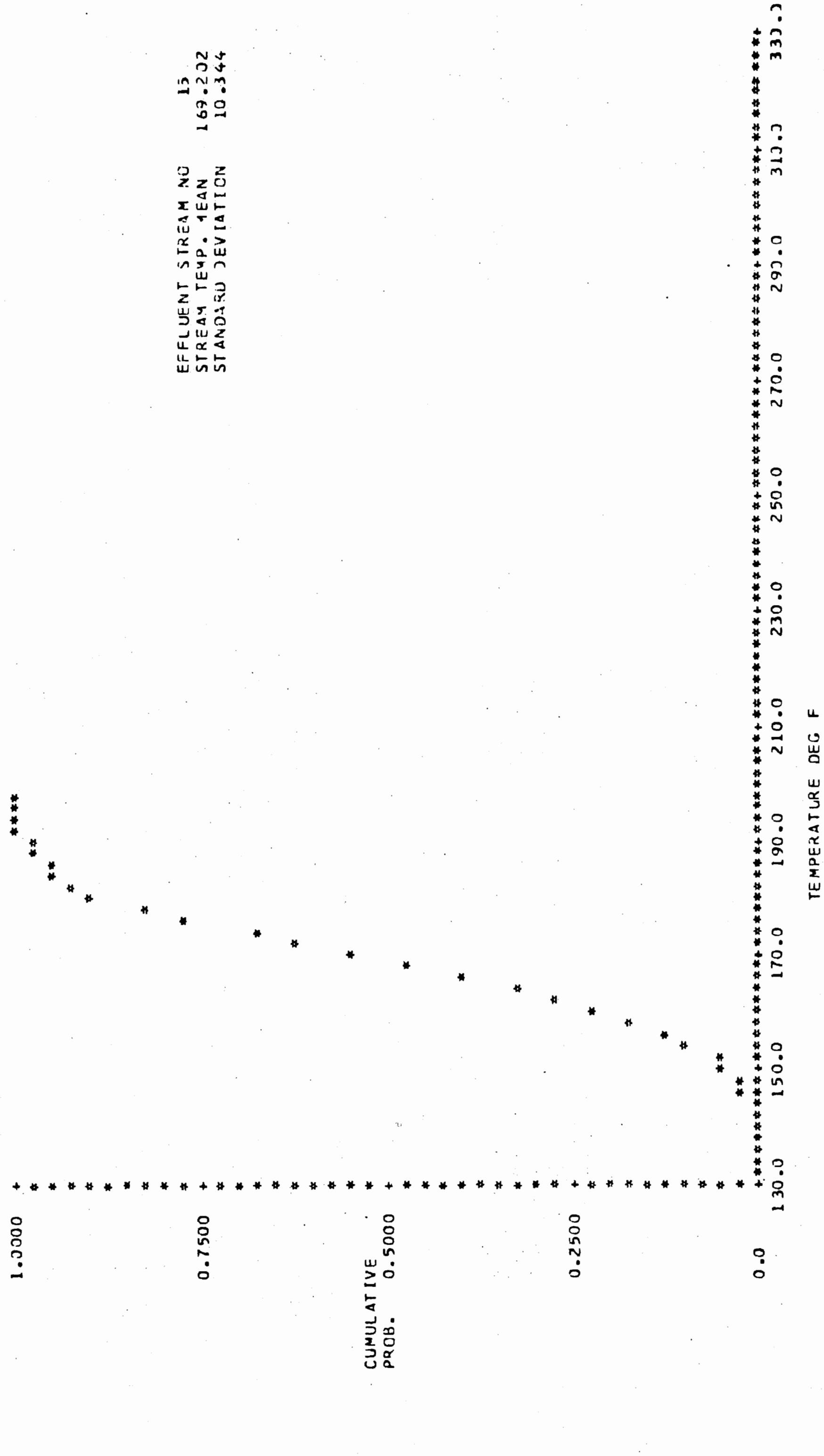
STREAM NUMBER	28	8	15	72	47	78	52	56	43	81
FLOW RATE LB/HR	712670.00	171310.00	10380.00	91216.00	69062.00	144039.00	94220.00	361150.00	712670.00	86166.00
TEMPERATURE DEG F	228.02	233.97	170.10	254.31	266.79	308.11	328.71	405.90	384.92	521.81
HEAT CAPACITY BTU/LB F	0.50200	2.64120	16.43298	0.65300	0.59500	0.66100	0.61200	0.64000	0.56600	0.73000
FLOW RATE STD LB/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD DEG F	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT CPY STD BTU/LB F	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

STREAM NUMBER	67
FLOW RATE LB/HR	634300.00
TEMPERATURE DEG F	476.92
HEAT CAPACITY BTU/LB F	0.70000
FLOW RATE STD LB/HR	0.0
TEMPERATURE STD DEG F	0.0
HEAT CPY STD BTU/LB F	0.0



EFFLUENT STREAM NO 23
STREAM TEMP. MEAN 227.136
STANDARD DEVIATION 10.414
1.0000
0.7500
CUMULATIVE
PROB. 0.5000
0.2500
0.0
190.0
210.0
230.0
250.0
270.0
290.0
310.0
330.0
350.0
370.0
390.0
TEMPERATURE DEG F


EFFLUENT STREAM NO 3
STREAM TEMP. MEAN 233.252
STANDARD DEVIATION 10.389
CUMULATIVE PROB.
1.0000
0.7500
0.5000
0.2500
0.0
200.0
220.0
240.0
260.0
280.0
300.0
320.0
340.0
360.0
380.0
400.0
TEMPERATURE DEG F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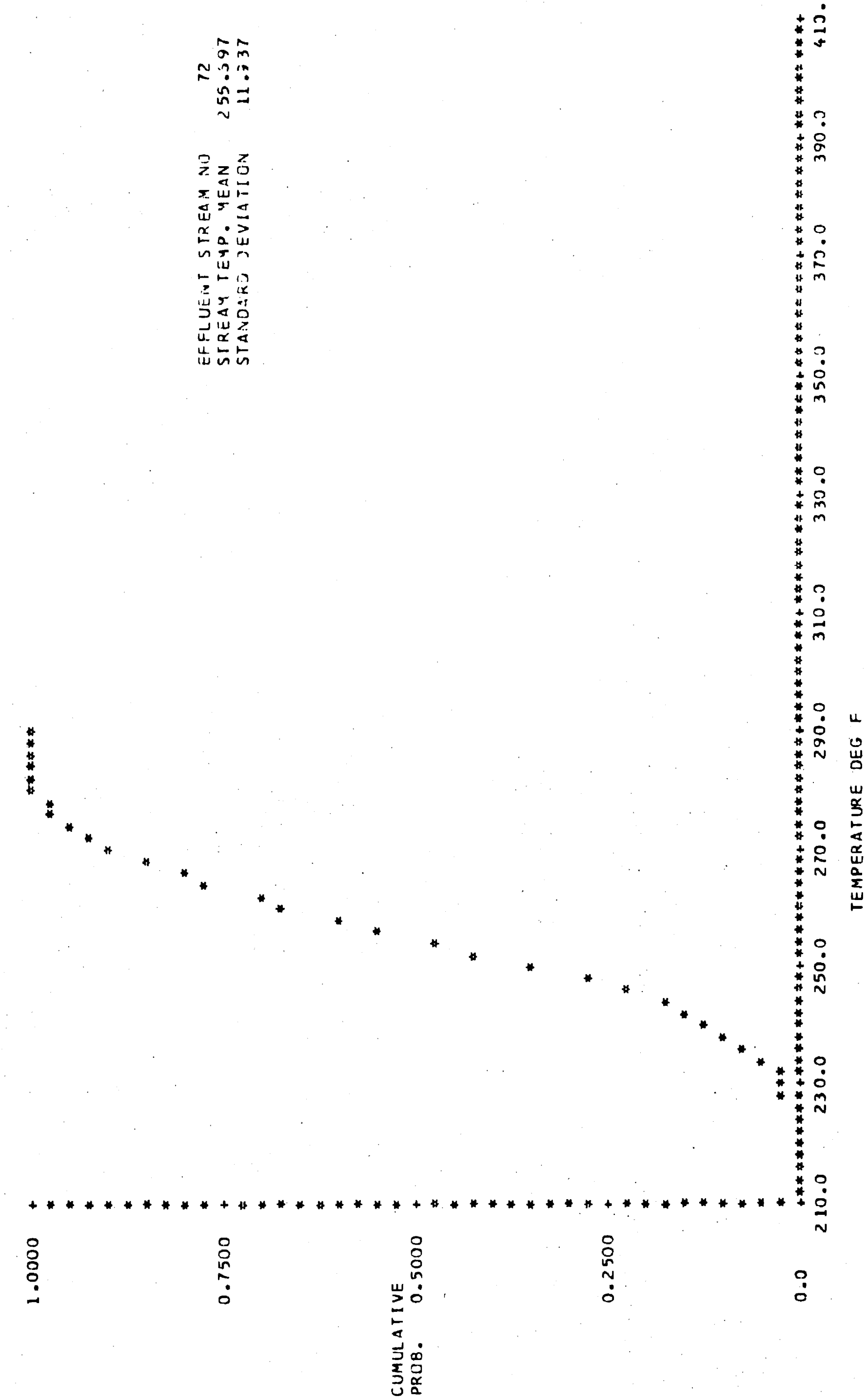
STREAM TEMP. MEAN 169.202
STANDARD DEVIATION 10.344
CUMULATIVE PROB.
1.0000
0.7500
0.5000
0.2500
0.0
130.0
150.0
170.0
190.0
210.0
230.0
250.0
270.0
290.0
310.0
330.0
TEMPERATURE DEG F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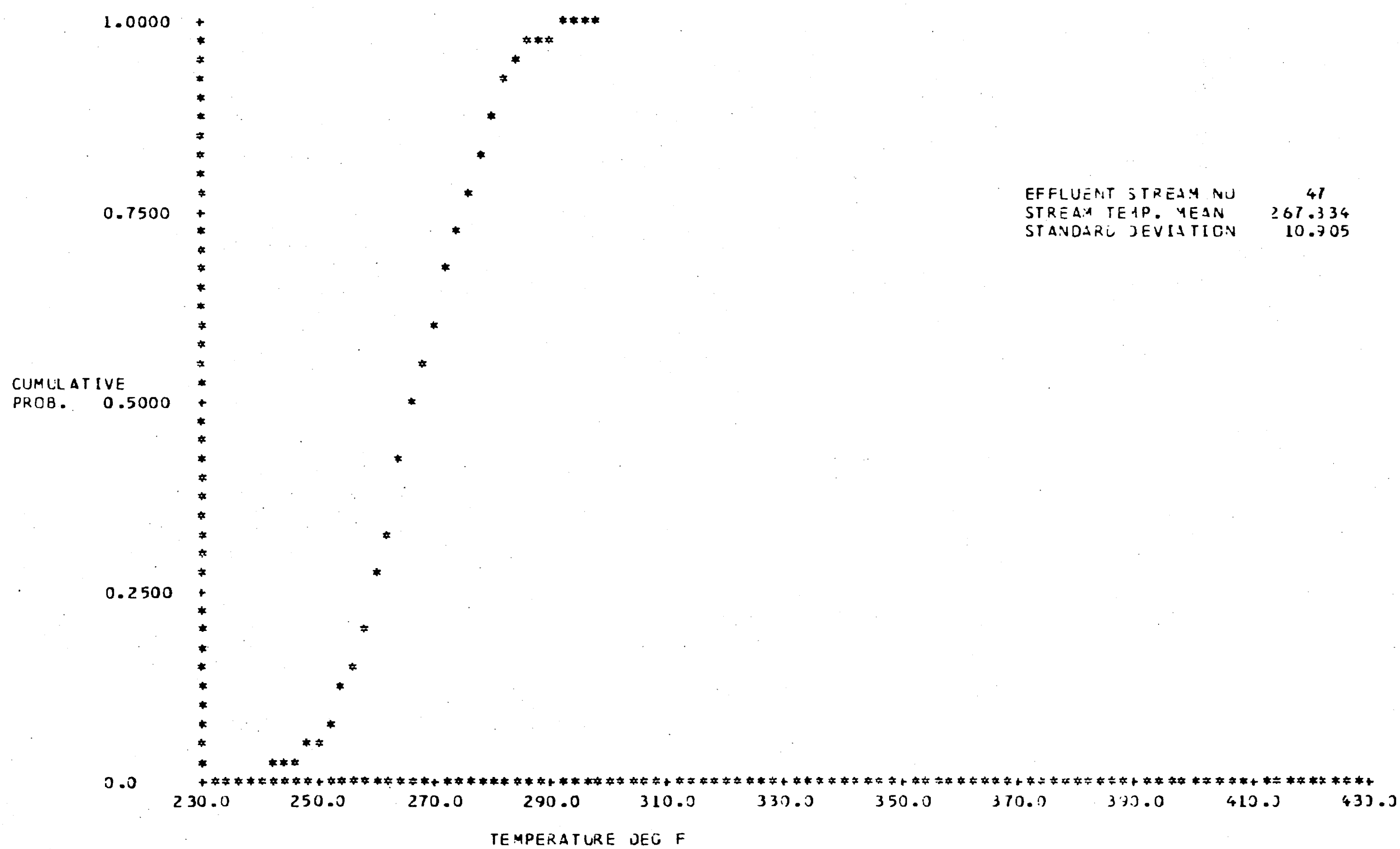
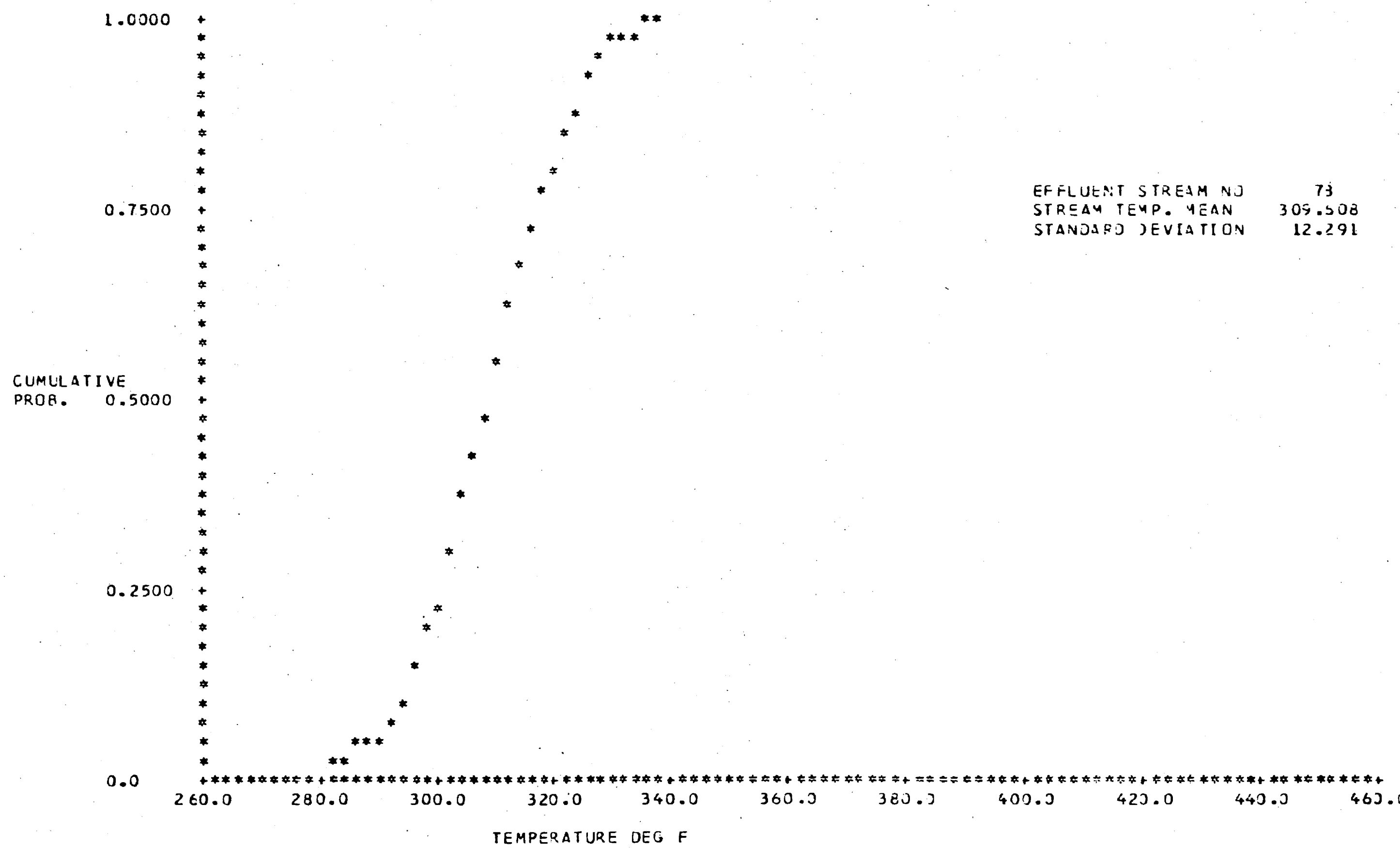
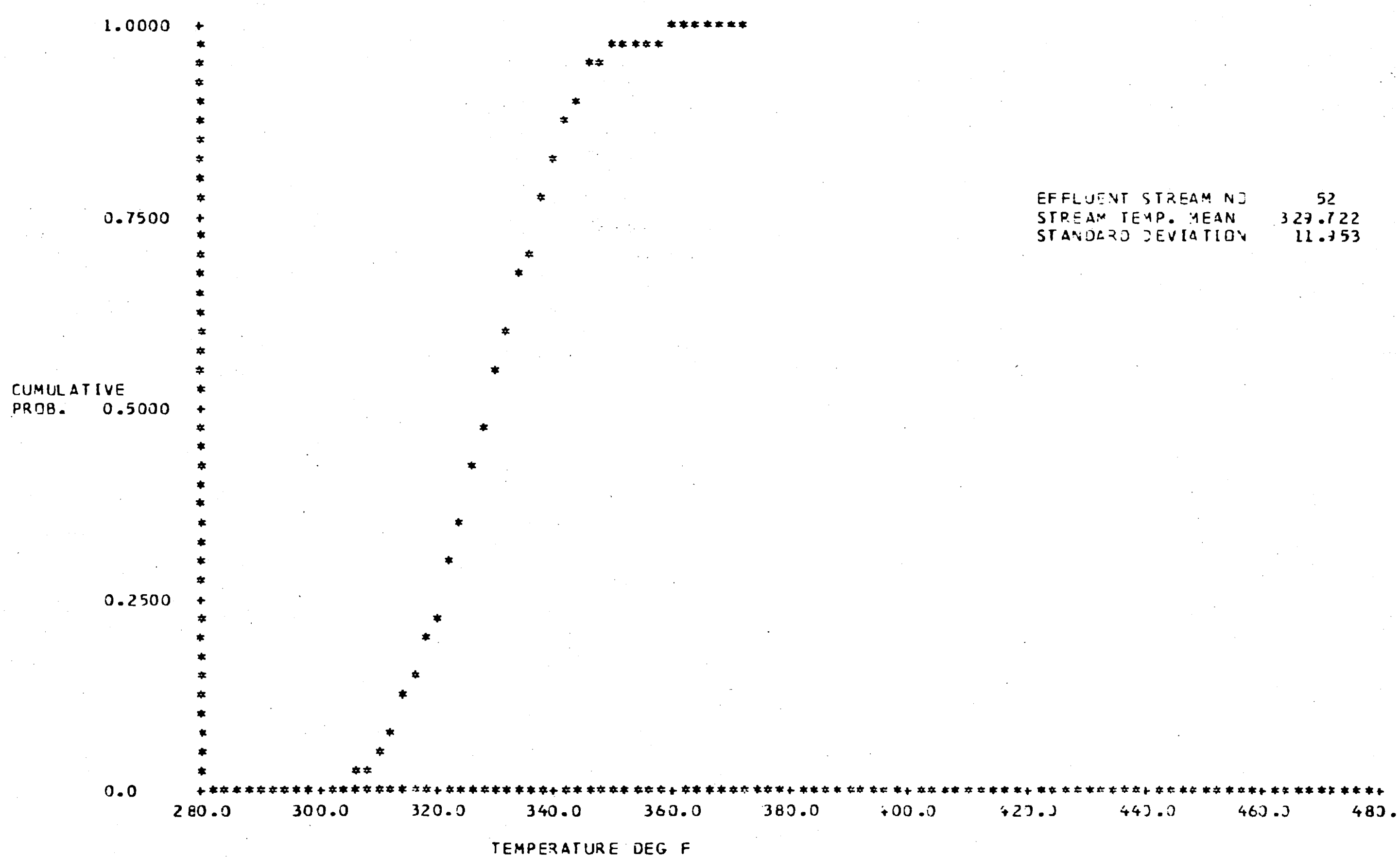
STREAM TEMP. MEAN 255.597
STANDARD DEVIATION 11.737
CUMULATIVE PROB.
1.0000
0.7500
0.5000
0.2500
0.0
210.0
230.0
250.0
270.0
290.0
310.0
330.0
350.0
370.0
390.0
410.0
TEMPERATURE DEG F

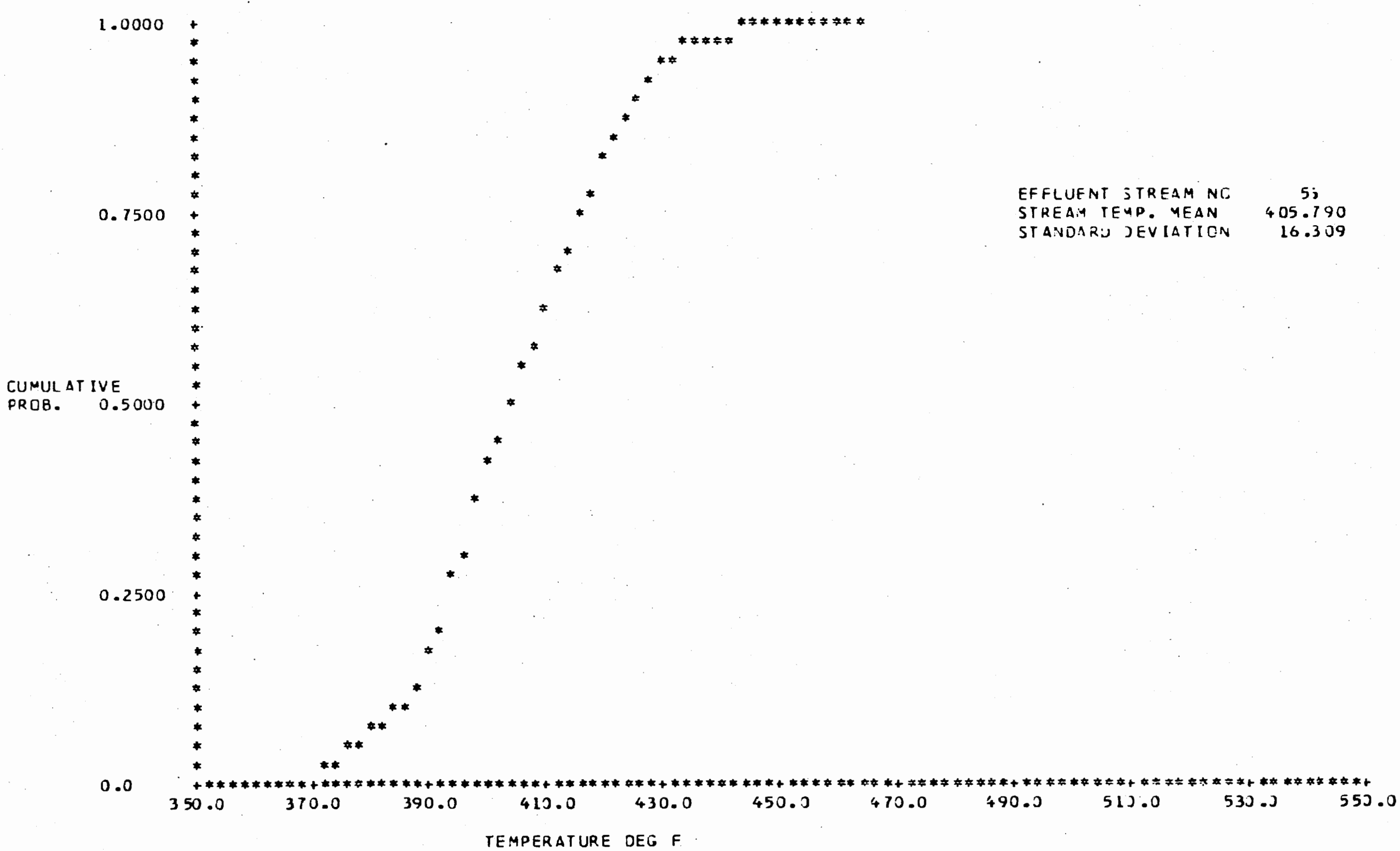


EFFLUENT STREAM NO 47
STREAM TEMP. MEAN 267.334
STANDARD DEVIATION 10.905

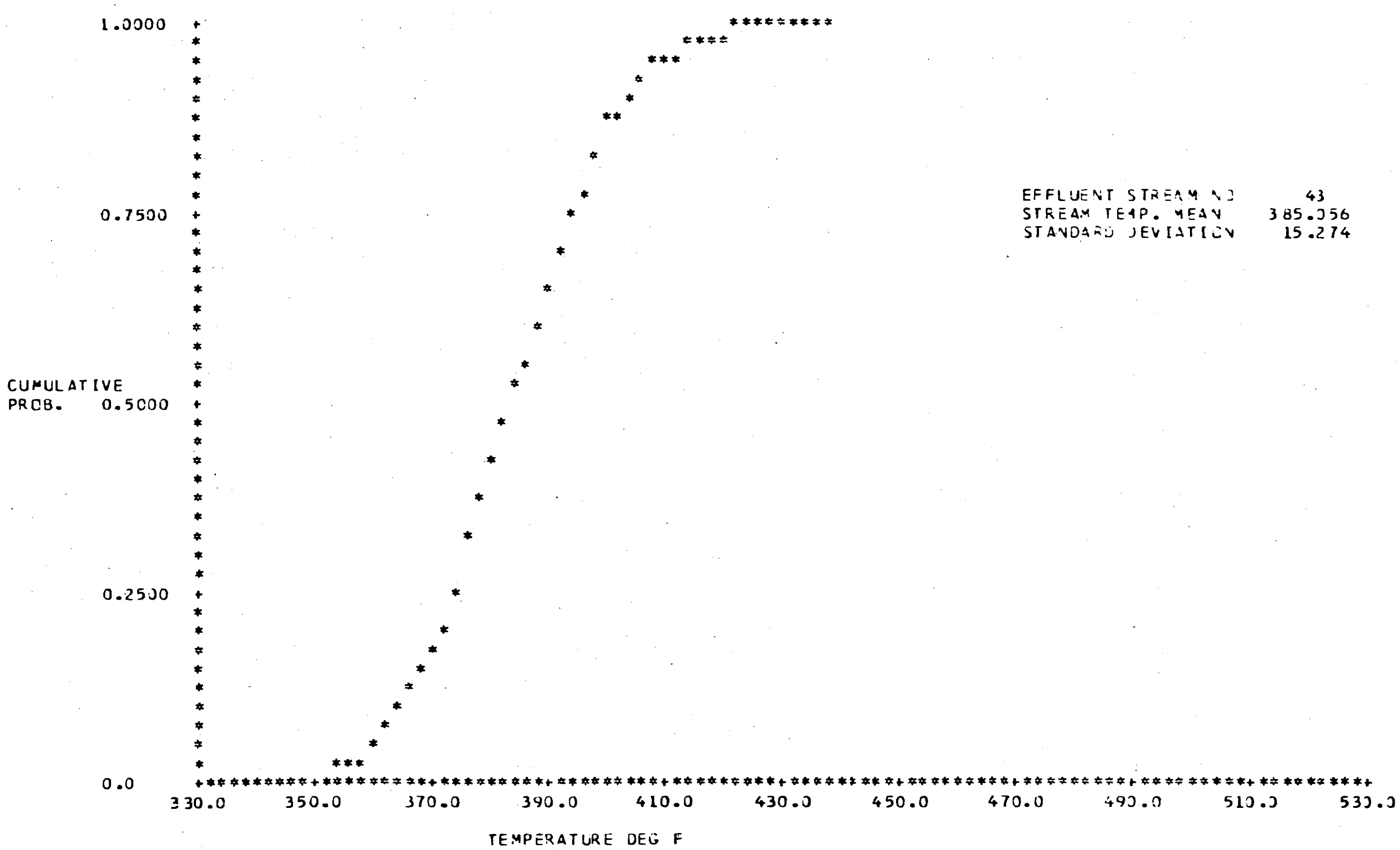

1.0000
0.7500
CUMULATIVE
PROB. 0.5000
0.2500
0.0
260.0
280.0
300.0
320.0
340.0
360.0
380.0
400.0
420.0
440.0
460.0
TEMPERATURE DEG F
EFFLUENT STREAM NO 73
STREAM TEMP. MEAN 309.508
STANDARD DEVIATION 12.291



EFFLUENT STREAM NO 52
STREAM TEMP. MEAN 329.722
STANDARD DEVIATION 11.953
1.0000
0.7500
CUMULATIVE PROB. 0.5000
0.2500
0.0
280.0
300.0
320.0
340.0
360.0
380.0
400.0
420.0
440.0
460.0
480.0
TEMPERATURE DEG F



1.0000
0.7500
CUMULATIVE
PROB. 0.5000
0.2500
0.0
350.0
370.0
390.0
410.0
430.0
450.0
470.0
490.0
510.0
530.0
550.0
TEMPERATURE DEG F
EFFLUENT STREAM NO 55
STREAM TEMP. MEAN 405.790
STANDARD DEVIATION 16.309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0.7500
CUMULATIVE
PROB. 0.5000
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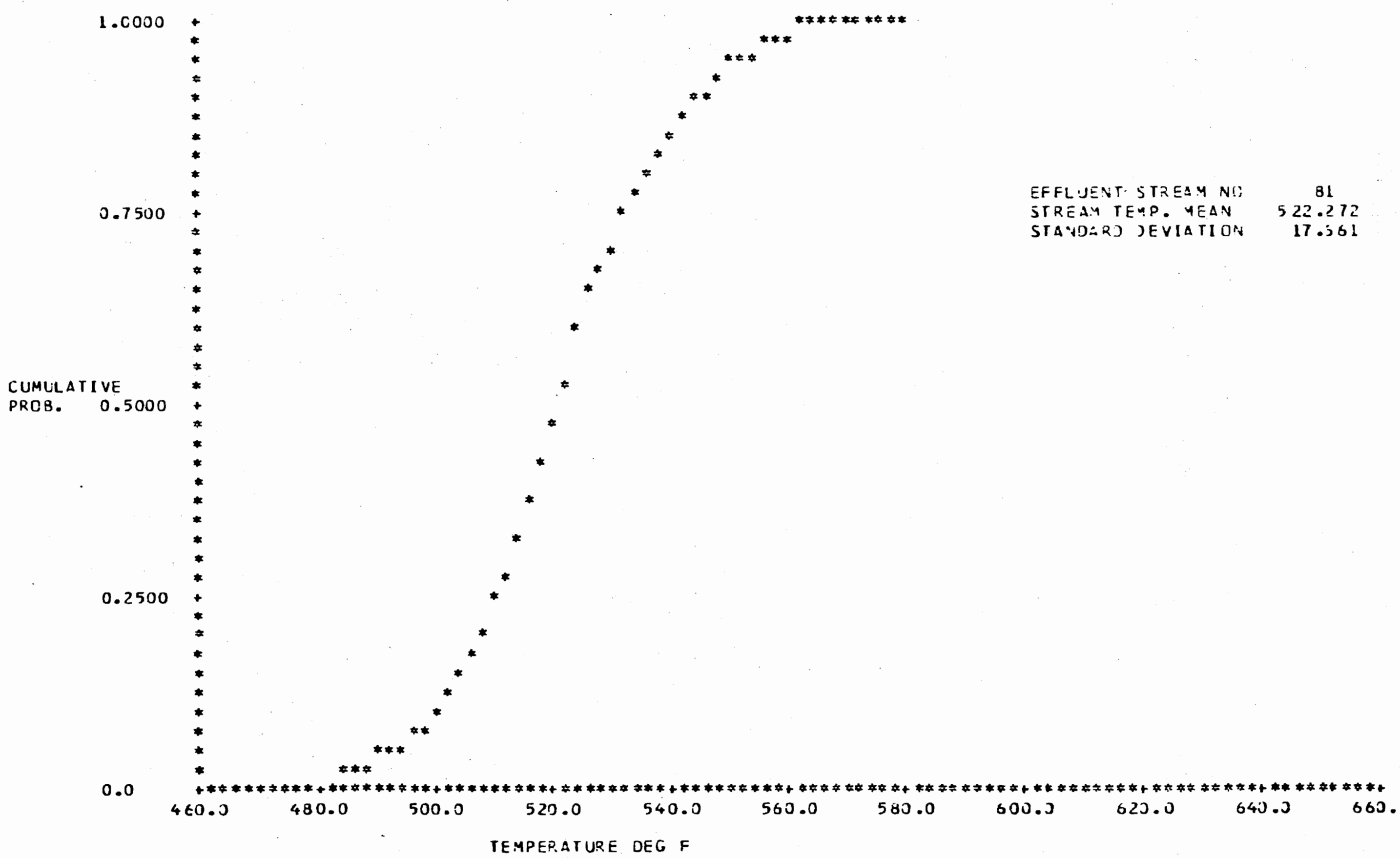
0.0
330.0
350.0
370.0
390.0
410.0
430.0
450.0
470.0
490.0
510.0
530.0
TEMPERATURE DEG F
EFFLUENT STREAM NO 43
STREAM TEMP. MEAN 385.056
STANDARD DEVIATION 15.274



EFFLUENT STREAM NO 81
STREAM TEMP. MEAN 522.272
STANDARD DEVIATION 17.361
CUMULATIVE PROB.
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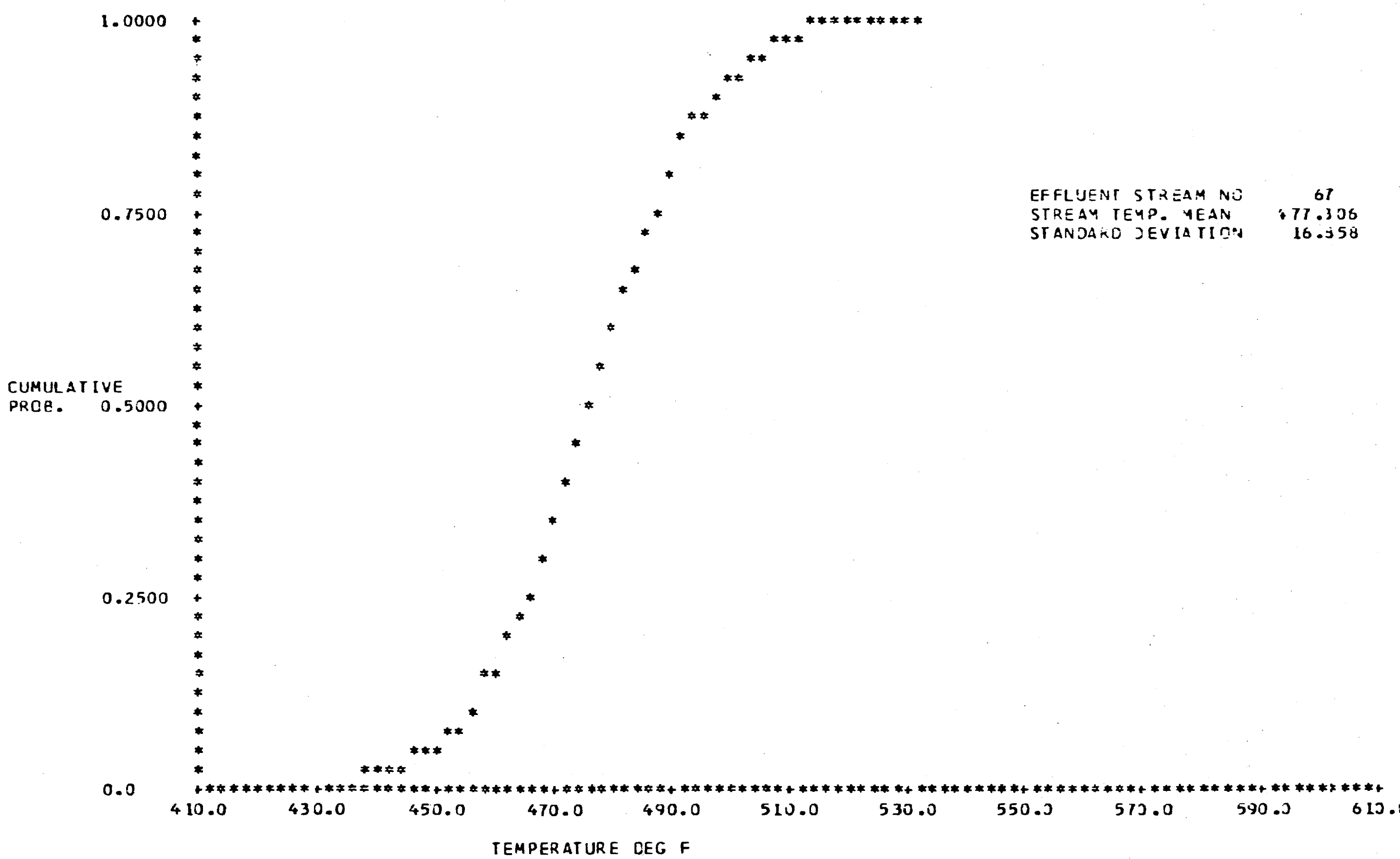
TEMPERATURE DEG F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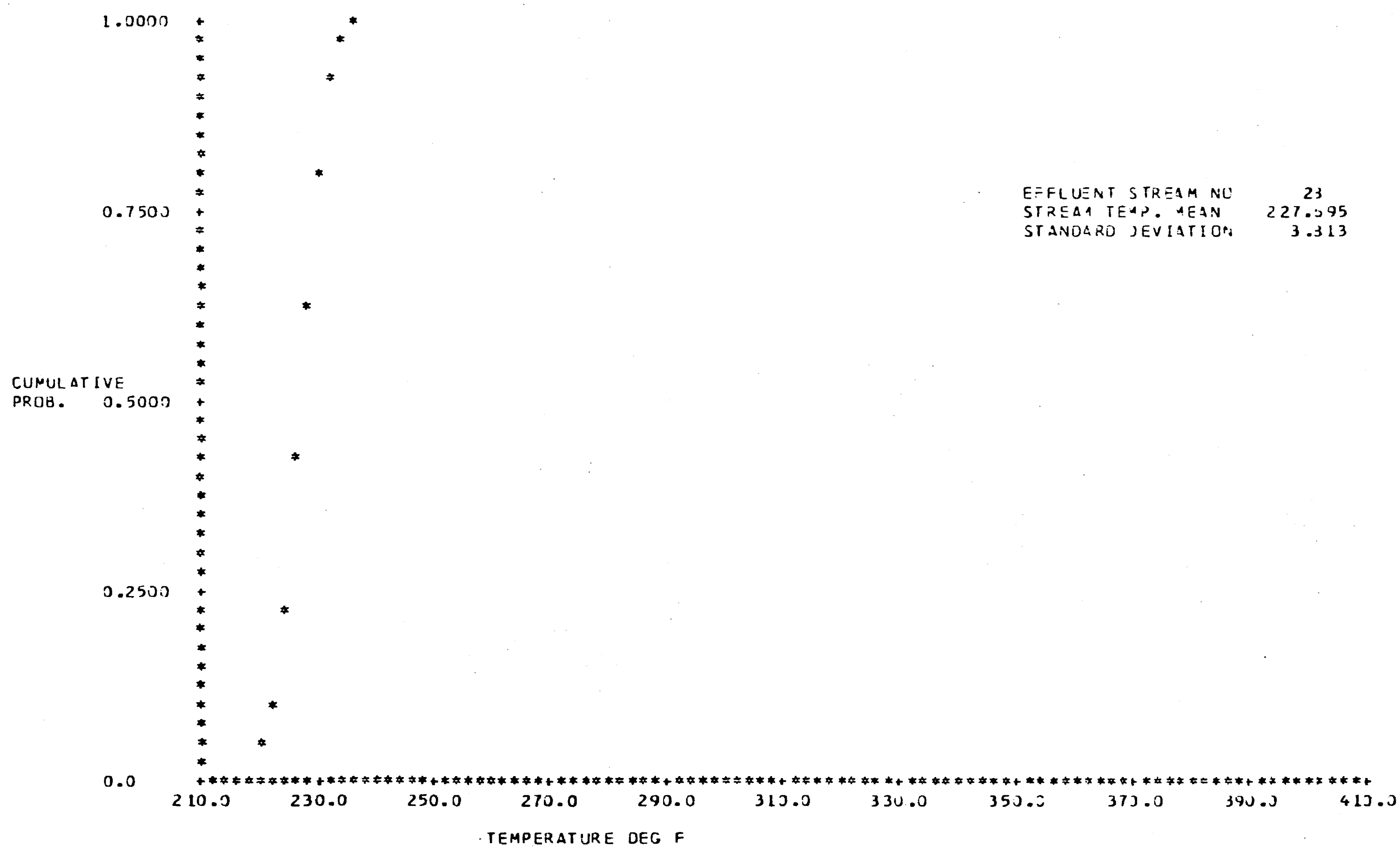
CUMULATIVE
PROB. 0.5000
0.2500
0.0
410.0
430.0
450.0
470.0
490.0
510.0
530.0
550.0
570.0
590.0
610.0
TEMPERATURE DEG F
EFFLUENT STREAM NO 67
STREAM TEMP. MEAN 477.306
STANDARD DEVIATION 16.358

APPENDIX B

PART OF THE RESULTS OF THE TEMPERATURE CALCULATION OF THE CRUDE PREHEAT TRAIN FOR THE CASE OF 1% AND 5% COEFFICIENTS OF VARIATION


EFFLUENT STREAM NO 23
STREAM TEMP. MEAN 227.595
STANDARD DEVIATION 3.313
CUMULATIVE PROB.
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0.2500
0.0
210.0
230.0
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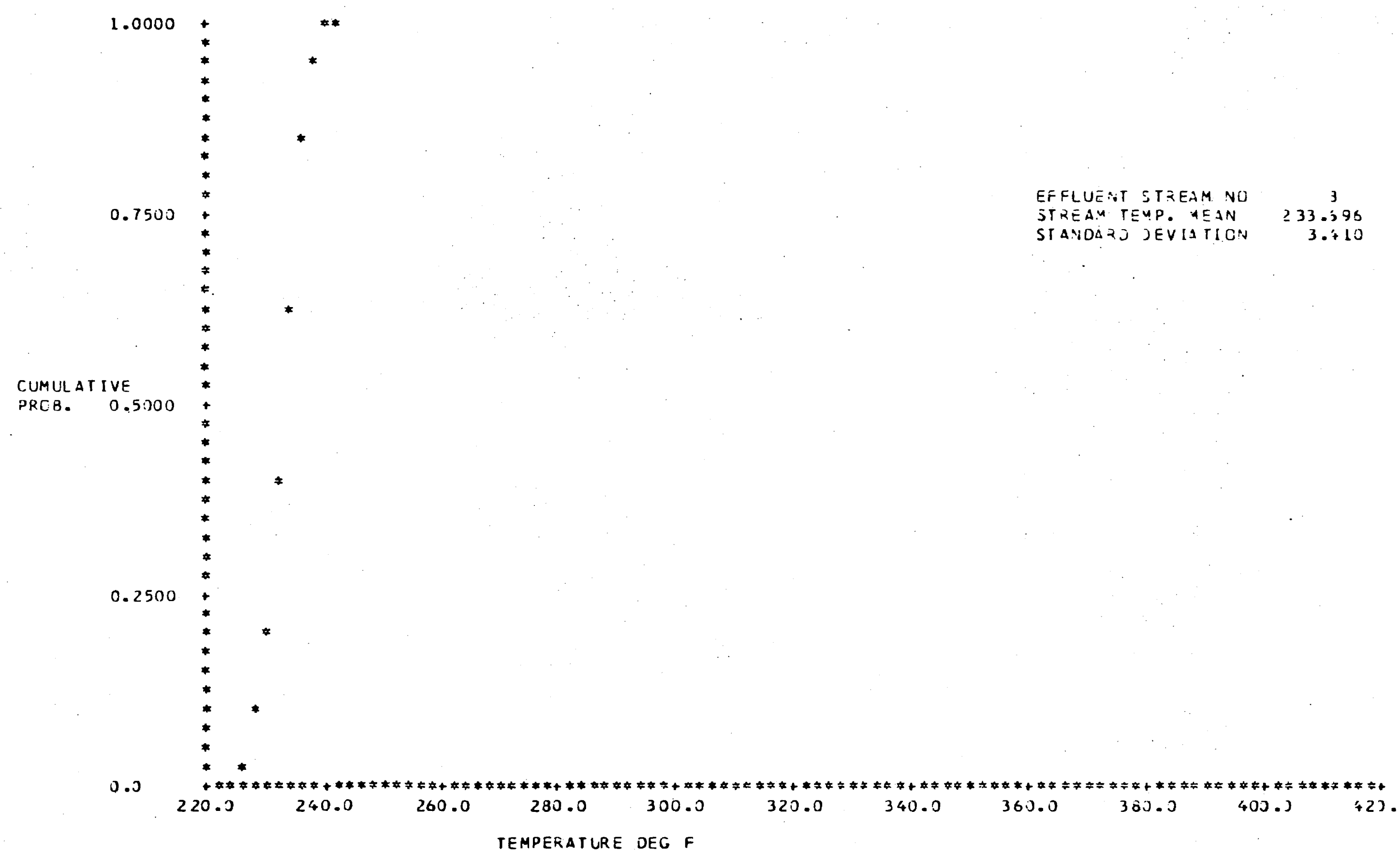
290.0
310.0
330.0
350.0
370.0
390.0
410.0
TEMPERATURE DEG F


EFFLUENT STREAM NO 3
STREAM TEMP. MEAN 233.596
STANDARD DEVIATION 3.410
CUMULATIVE PROB.
1.0000
0.7500
0.5000
0.2500
0.0
220.0
240.0
260.0
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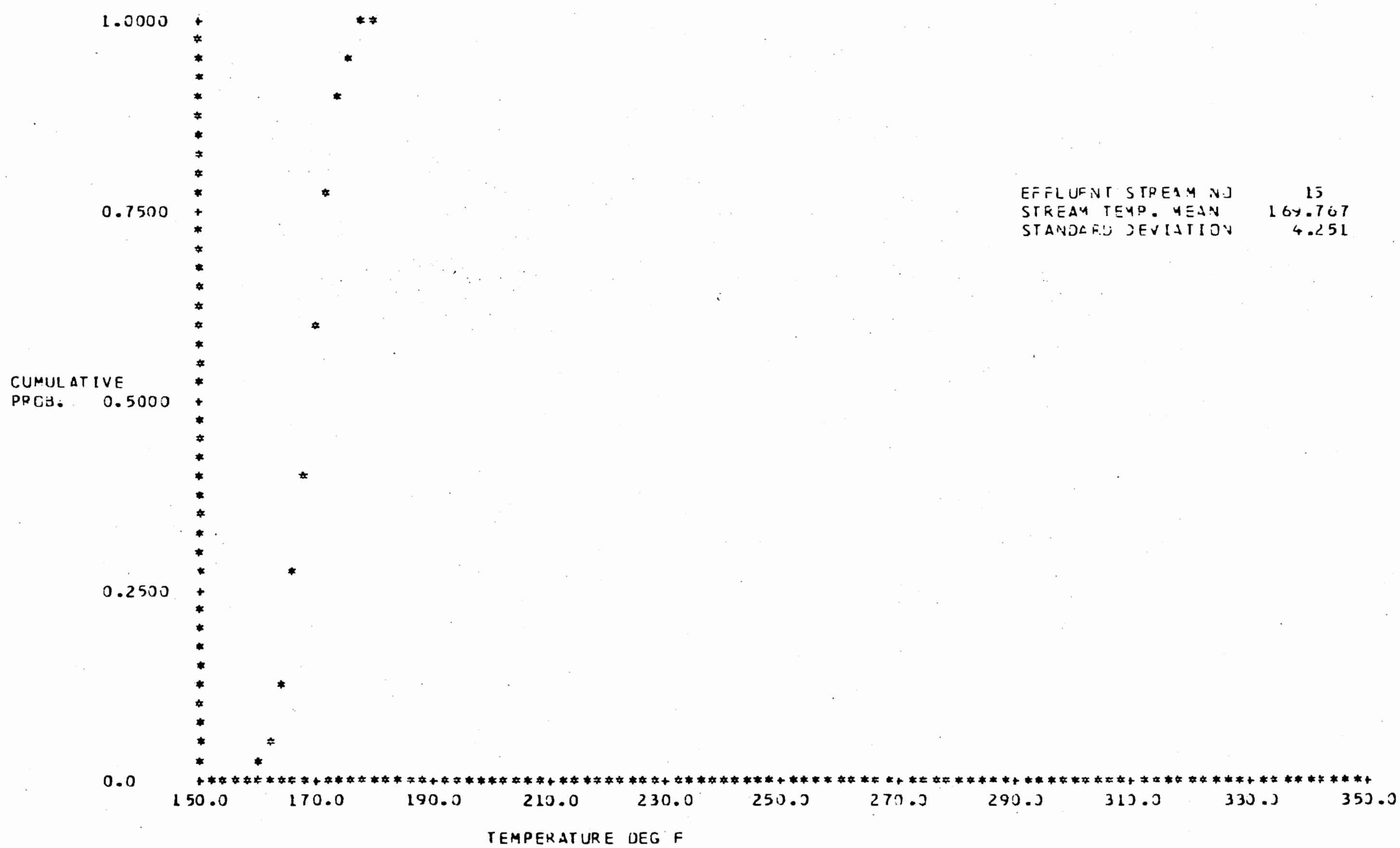
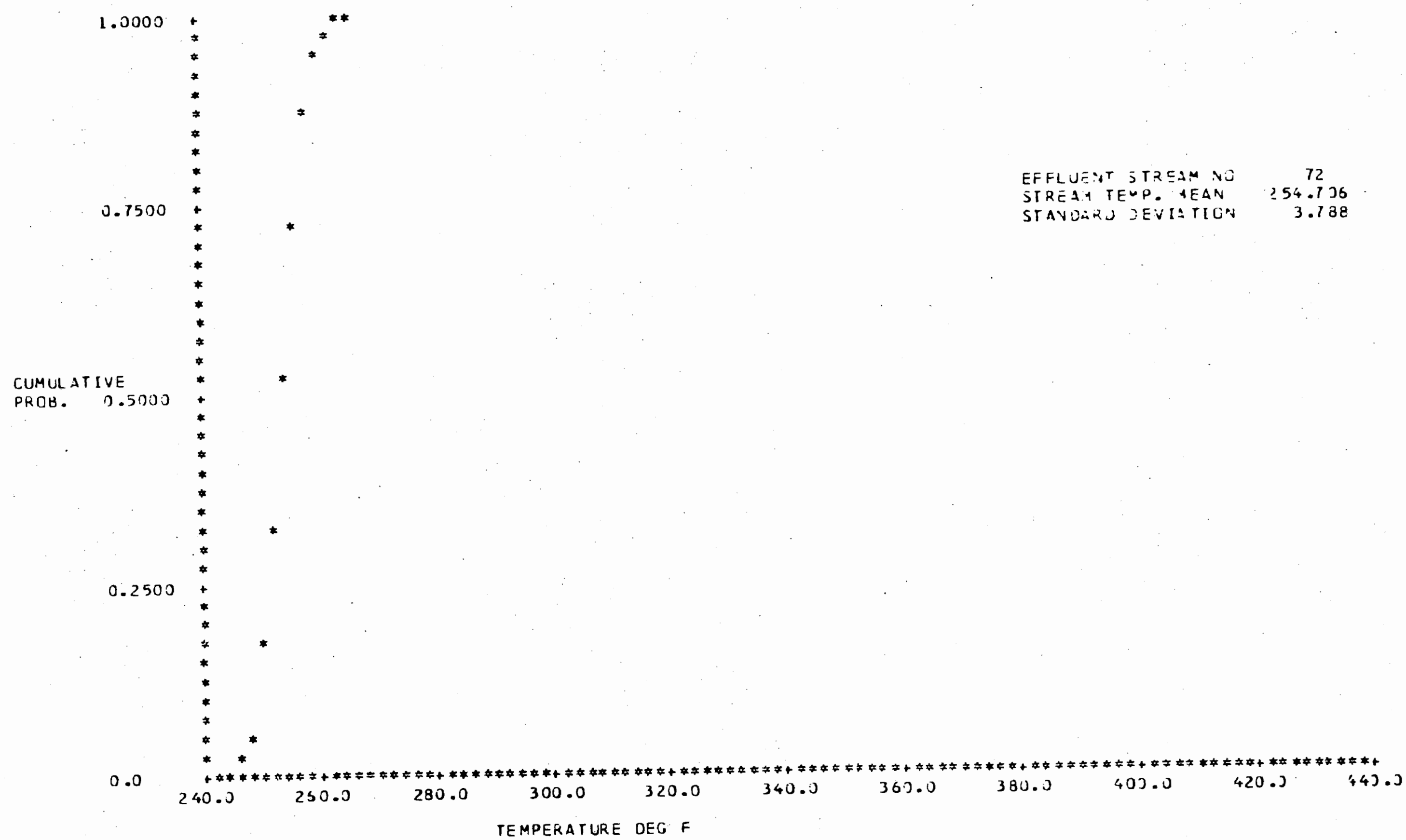
360.0
380.0
400.0
420.0
TEMPERATURE DEG F



EFFLUENT STREAM NO 15
STREAM TEMP. MEAN 169.767
STANDARD DEVIATION 4.251
1.0000
0.7500
CUMULATIVE PROB. 0.5000
0.2500
0.0
150.0
170.0
190.0
210.0
230.0
250.0
270.0
290.0
310.0
330.0
350.0
TEMPERATURE DEG F


EFFLUENT STREAM NO 72
STREAM TEMP. MEAN 254.706
STANDARD DEVIATION 3.788
CUMULATIVE PROB.
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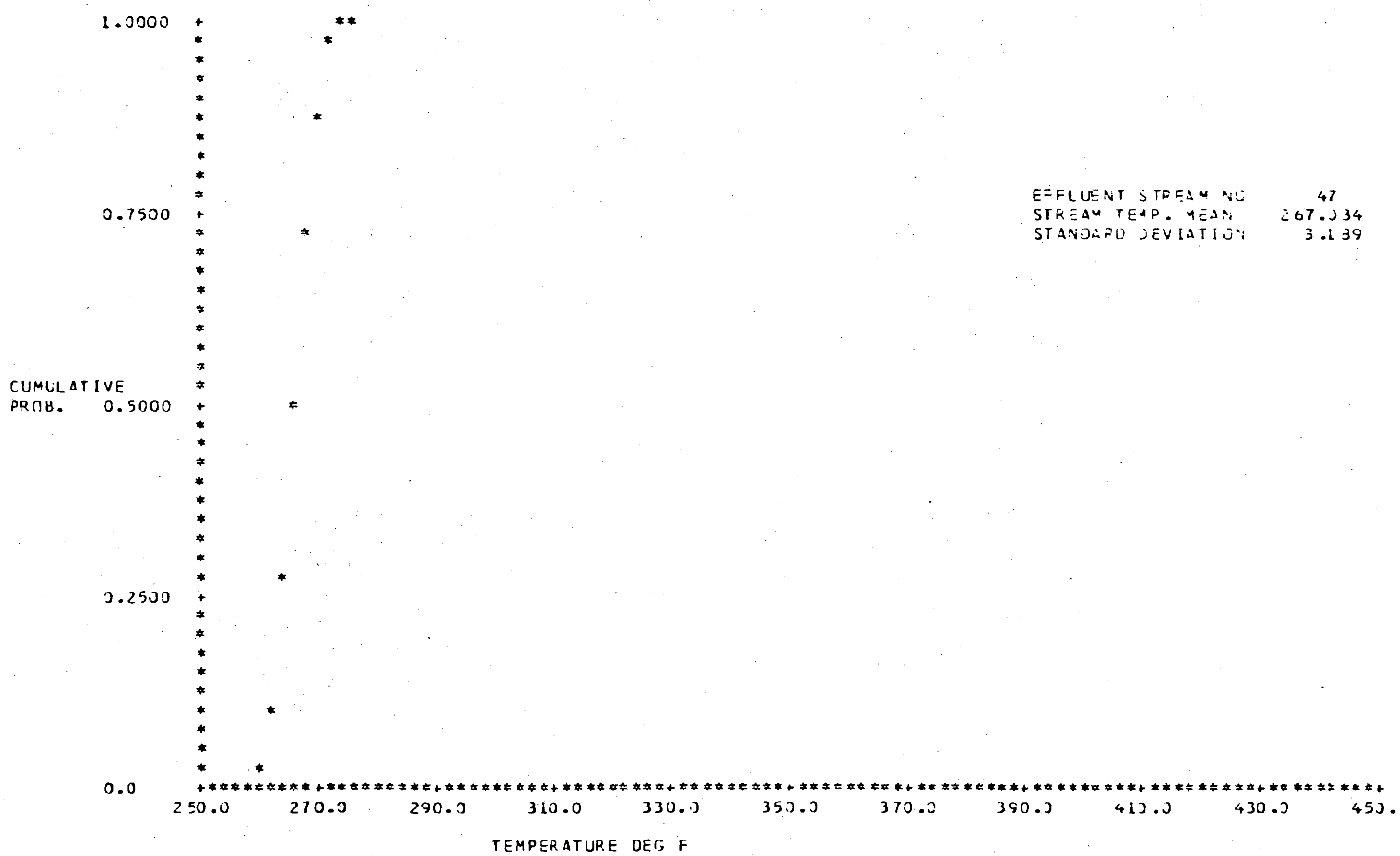
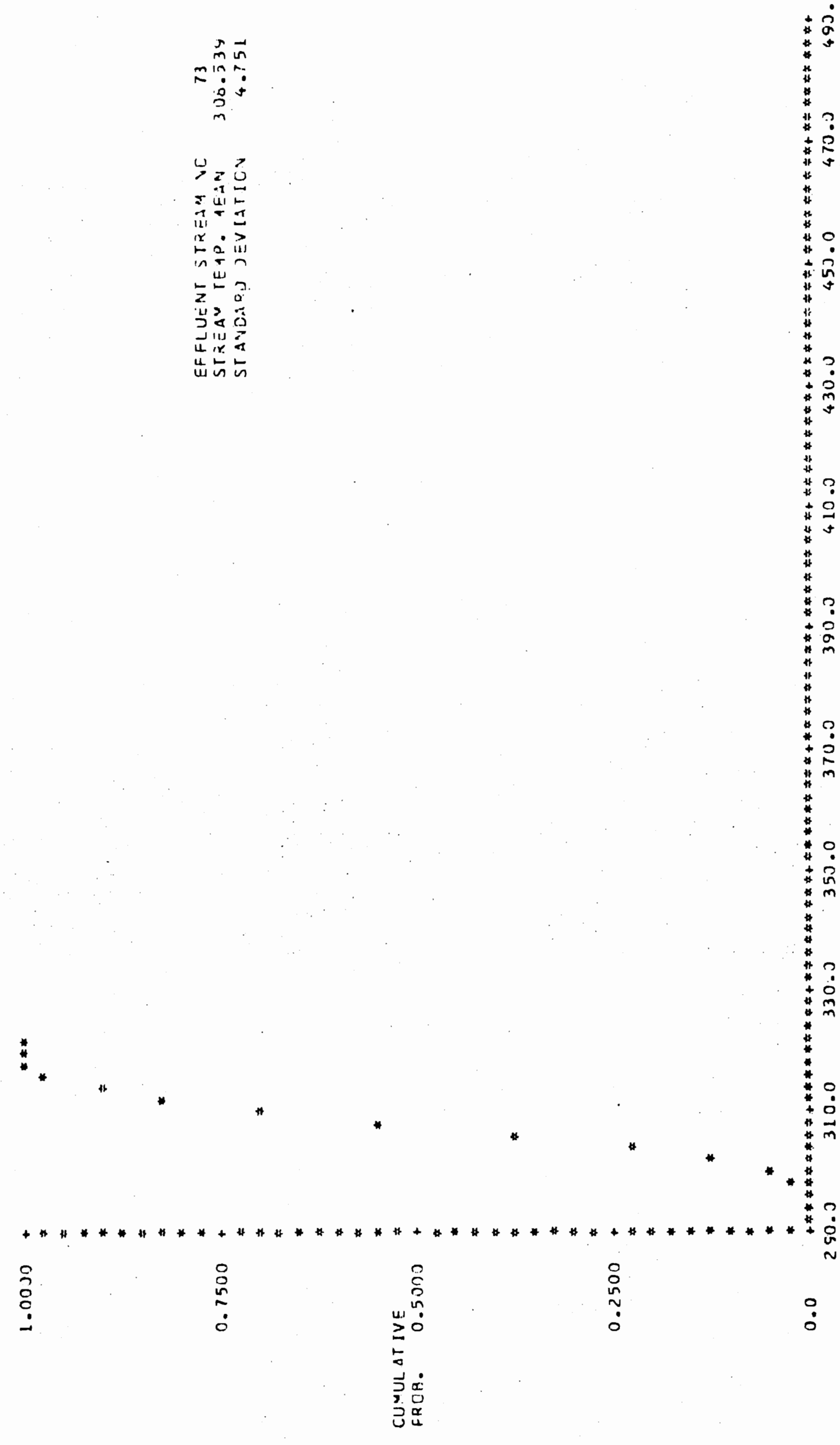
0.5000
0.2500
0.0
240.0
260.0
280.0
300.0
320.0
340.0
360.0
380.0
400.0
420.0
440.0
TEMPERATURE DEG F


1.0000
0.7500
CUMULATIVE
PROB. 0.5000
0.2500
0.0
250.0
270.0
290.0
310.0
330.0
350.0
370.0
390.0
410.0
430.0
450.0
TEMPERATURE DEG F
EFFLUENT STREAM NO 47
STREAM TEMP. MEAN 267.034
STANDARD DEVIATION 3.139



EFFLUENT STREAM NO 73
STREAM TEMP. MEAN 306.539
STANDARD DEVIATION 4.751
CUMULATIVE PROB.
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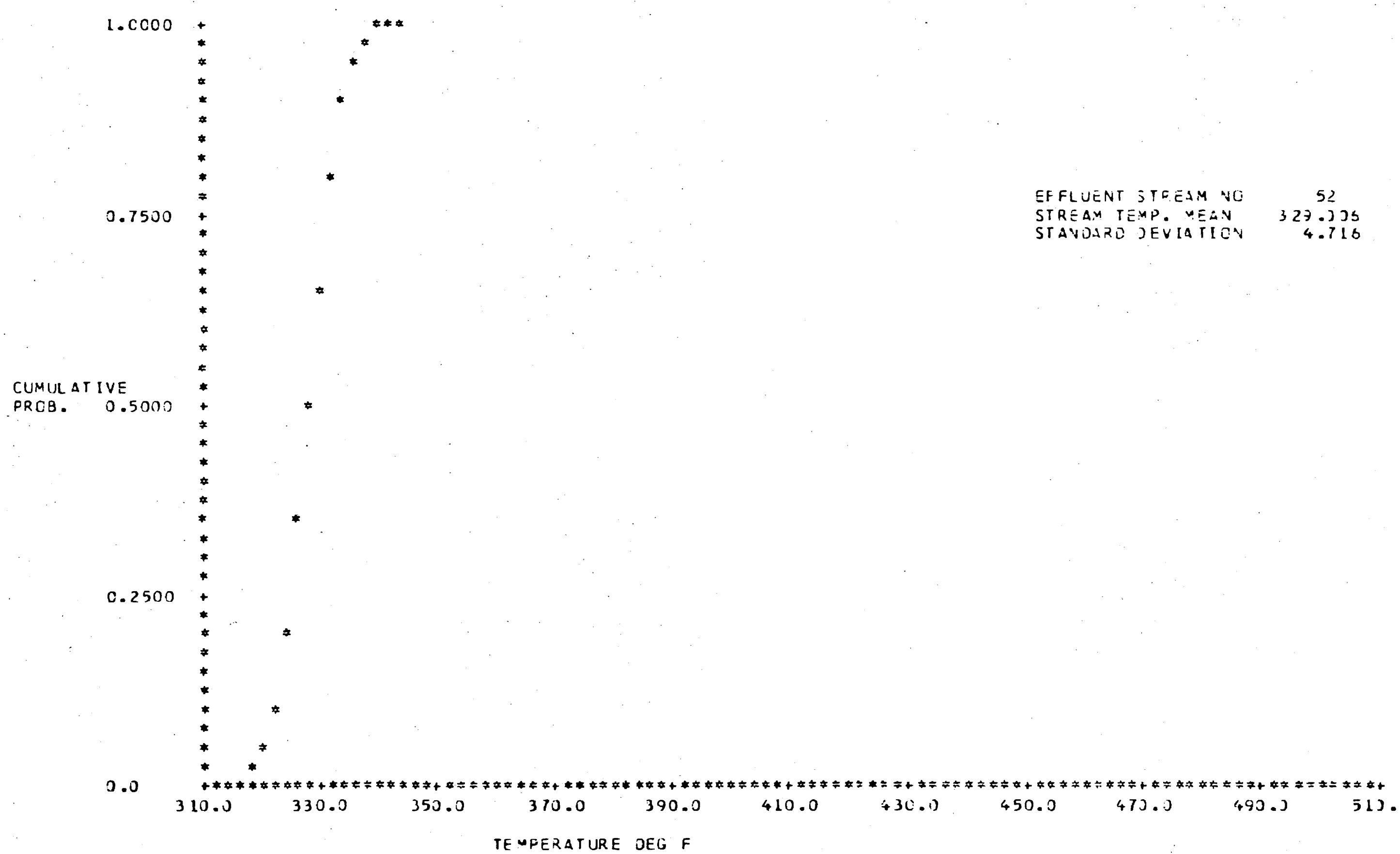
0.5000
0.2500
0.0
290.0
310.0
330.0
350.0
370.0
390.0
410.0
430.0
450.0
470.0
490.0
TEMPERATURE DEG F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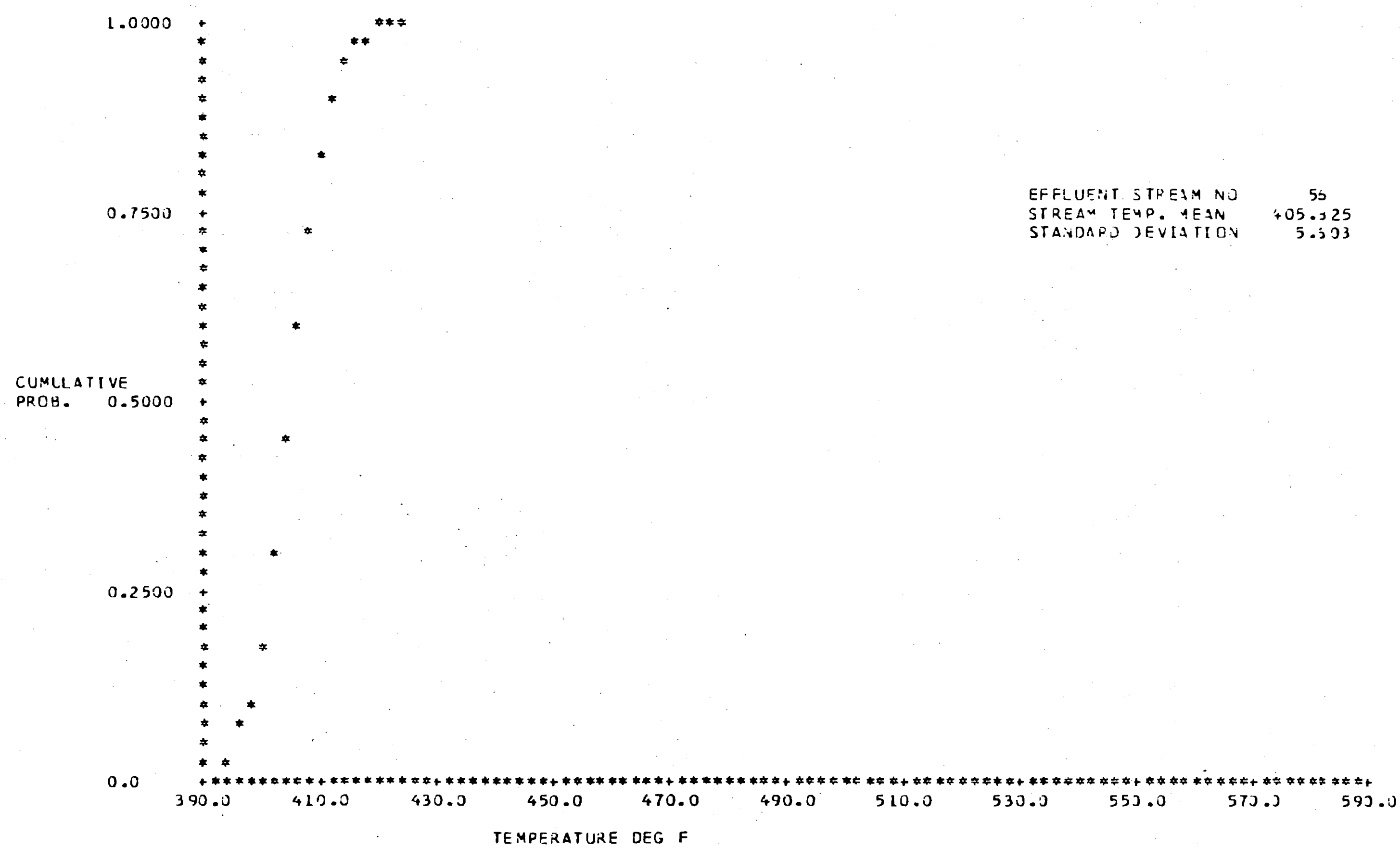
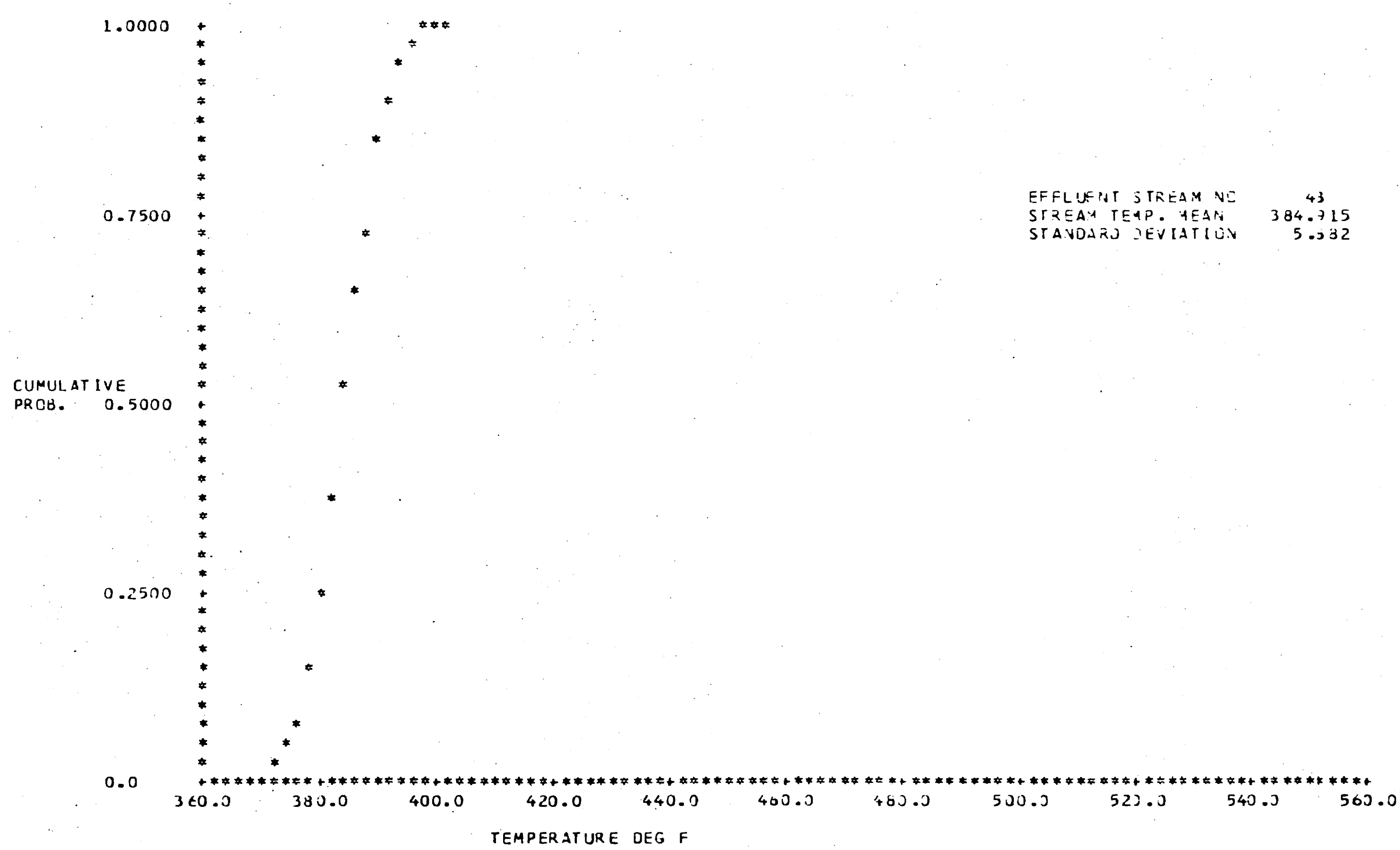
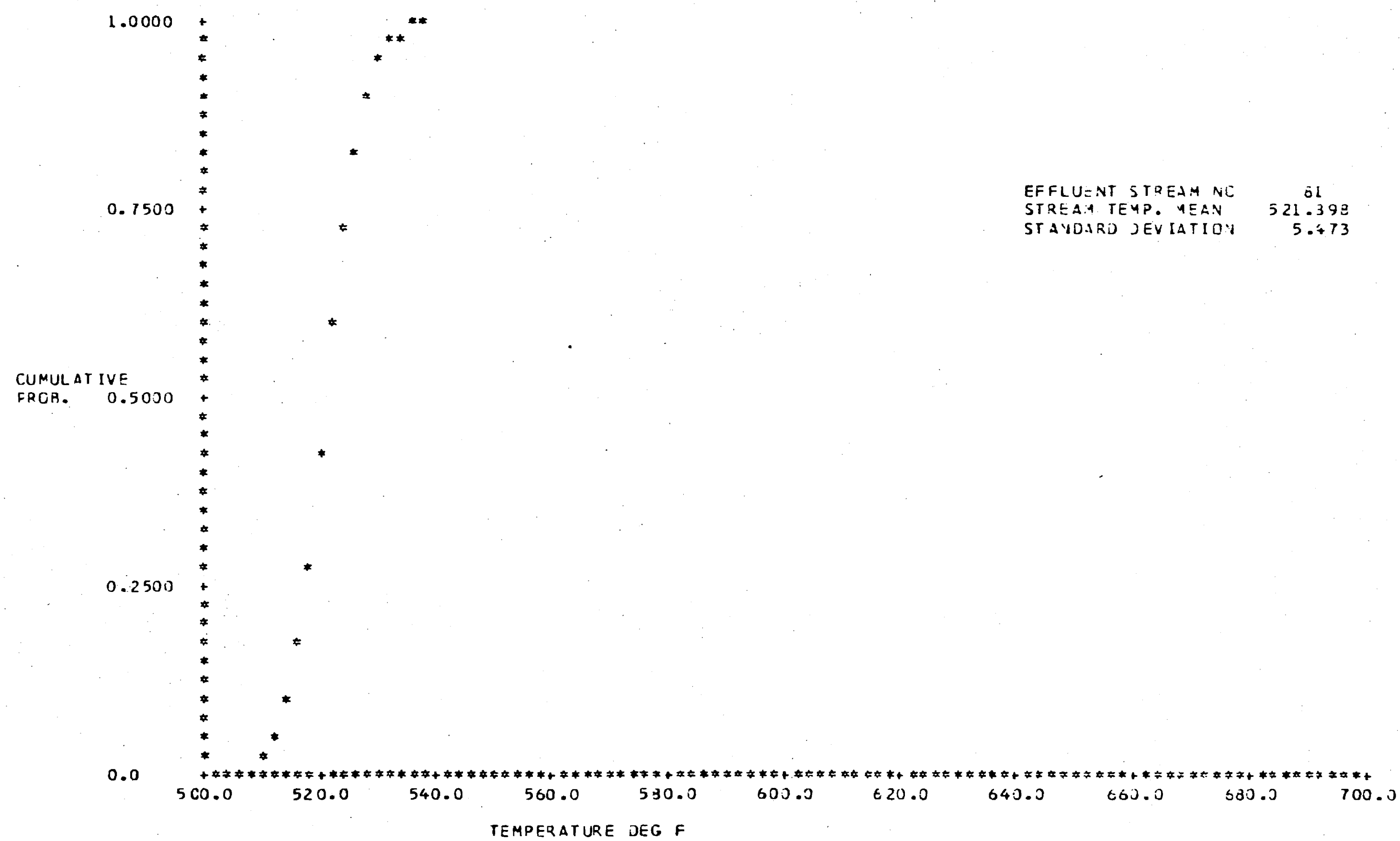
0.7500
CUMULATIVE
PROB. 0.5000
0.2500
0.0
310.0 330.0 350.0 370.0 390.0 410.0 430.0 450.0 470.0 490.0 510.0
TEMPERATURE DEG F
EFFLUENT STREAM NO 52
STREAM TEMP. MEAN 329.006
STANDARD DEVIATION 4.716


1.0000
0.7500
CUMULATIVE
PROB. 0.5000
0.2500
0.0
390.0
410.0
430.0
450.0
470.0
490.0
510.0
530.0
550.0
570.0
590.0
TEMPERATURE DEG F
EFFLUENT STREAM NO 56
STREAM TEMP. MEAN 405.325
STANDARD DEVIATION 5.603


EFFLUENT STREAM NO 43
STREAM TEMP. MEAN 384.915
STANDARD DEVIATION 5.582
CUMULATIVE PROB.
1.0000
0.7500
0.5000
0.2500
0.0
360.0
380.0
400.0
420.0
440.0
460.0
480.0
500.0
520.0
540.0
560.0
TEMPERATURE DEG F


EFFLUENT STREAM NO 61
STREAM TEMP. MEAN 521.398
STANDARD DEVIATION 5.473
CUMULATIVE PROB.
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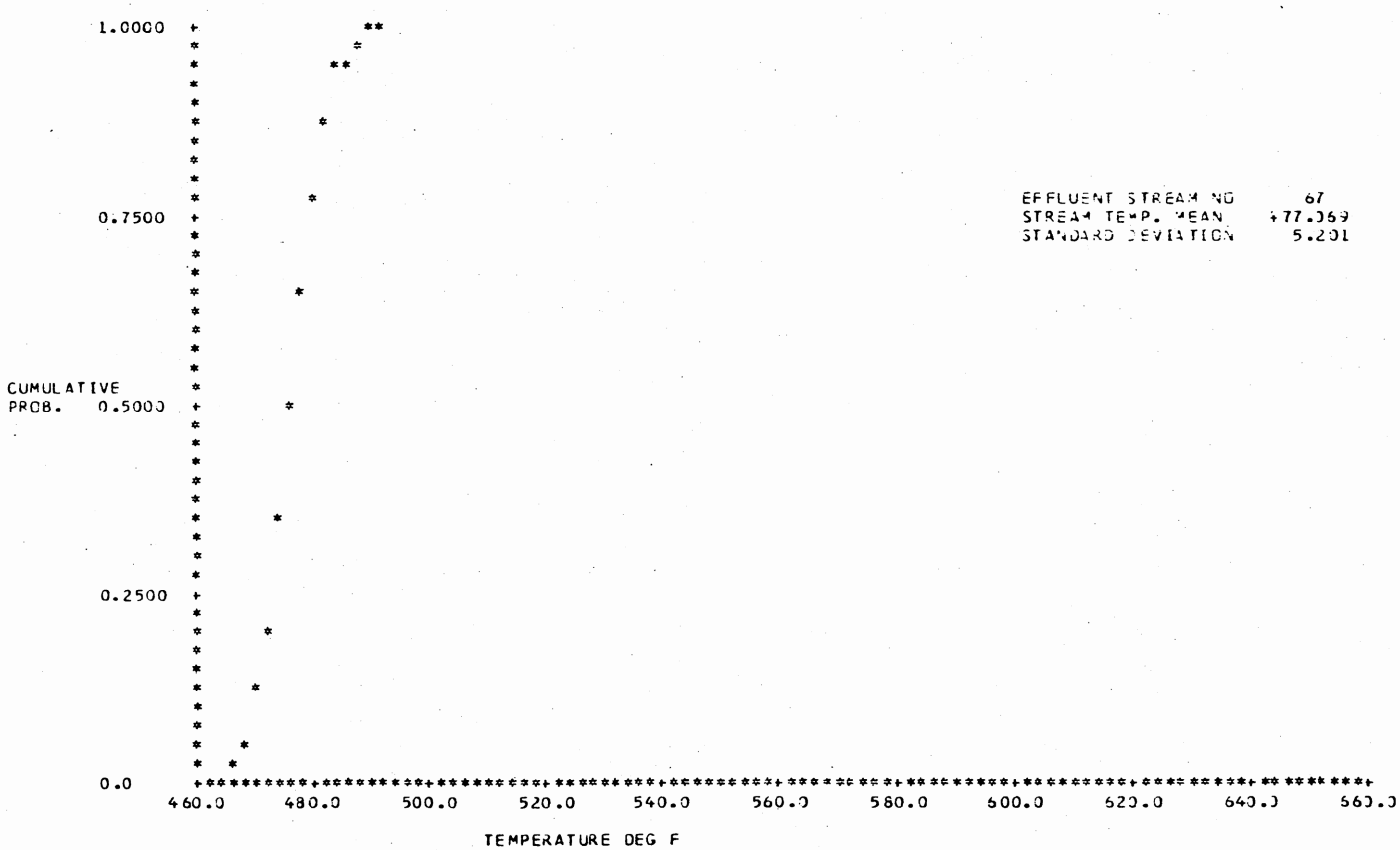
0.7500
0.5000
0.2500
0.0
500.0
520.0
540.0
560.0
580.0
600.0
620.0
640.0
660.0
680.0
700.0
TEMPERATURE DEG F


EFFLUENT STREAM NO 67
STREAM TEMP. MEAN 477.069
STANDARD DEVIATION 5.201
CUMULATIVE PROB.
1.0000
0.7500
0.5000
0.2500
0.0
460.0
480.0
500.0
520.0
540.0
560.0
580.0
600.0
620.0
640.0
660.0
TEMPERATURE DEG F

APPENDIX C

RESULTS OF THE AREA CALCULATION OF THE CRUDE PREHEAT TRAIN FOR THE CASE OF 5% AND 10% COEFFICIENTS OF VARIATION

STREAM DIVIDER

ELEMENT NUMBER** 3

NUMBER OF FEED STREAMS** 1 NUMBER OF PRODUCT STREAMS** 2

	FEED	PRODUCT			
STREAM NUMBER	16	17	23	0	0
FLOW RATE LB/HR	712670.00	356335.00	356335.00	0.0	0.0
TEMPERATURE,DEG F	94.00	94.00	94.00	0.0	0.0
HEAT CAPACITY,BTU/LB F	0.49300	0.49300	0.49300	0.0	0.0
FLOW RATE STD.LB/HR	35633.50	17816.75	17816.75	0.0	0.0
TEMPERATURE STD,DEG F	0.94	0.94	0.94	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0	0.0

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN *** OUTPUT LISTING ***

STREAM DIVIDER

ELEMENT NUMBER** 4

NUMBER OF FEED STREAMS** 1 NUMBER OF PRODUCT STREAMS** 2

	FEED	PRODUCT			
STREAM NUMBER	10	11	13	0	0
FLOW RATE LB/HR	10380.00	5190.00	5190.00	0.0	0.0
TEMPERATURE,DEG F	306.00	306.00	306.00	0.0	0.0
HEAT CAPACITY,BTU/LB F	16.43300	16.43300	16.43300	0.0	0.0
FLOW RATE STD,LB/HR	519.00	259.50	259.50	0.0	0.0
TEMPERATURE STD,DEG F	3.06	3.06	3.06	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0	0.0

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN

*** OUTPUT LISTING ***

STREAM DIVIDER

ELEMENT NUMBER** 5

NUMBER OF FEED STREAMS** 1 NUMBER OF PRODUCT STREAMS** 2

	FEED	PRODUCT			
STREAM NUMBER	1	2	5	0	0
FLOW RATE LB/HR	171310.00	85655.00	85655.00	0.0	0.0
TEMPERATURE,DEG F	284.00	284.00	284.00	0.0	0.0
HEAT CAPACITY,BTU/LB F	2.94300	2.94300	2.94300	0.0	0.0
FLOW RATE STD.LB/HR	8565.50	4282.75	4282.75	0.0	0.0
TEMPERATURE STD.DEG F	2.84	2.84	2.84	0.0	0.0
HEAT CAPACITY STD.BTU/LB F	0.0	0.0	0.0	0.0	0.0

HEAT EXCHANGER

ELEMENT NUMBER** 6

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	17	11	18	12
FLOW RATE,LB/HR	356335.00	5190.00	356335.00	5190.00
TEMPERATURE,DEG F	94.00	306.00	160.00	170.05
HEAT CAPACITY,BTU/LB F	0.49300	16.43300	0.49300	16.43300
FLOW RATE STD,LB/HR	17816.75	259.50	0.0	0.0
TEMPERATURE STD,DEG F	0.94	3.06	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	450.00000	22.50000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	295.00000	14.75000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00375	0.00019
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00160	0.00008
OVERALL COEFF.,BTU/SQR FT HR DEG F	77.12622	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT   PAR-CNTR

NUMBER OF SHELL-PASSES   1

ISOTHERMAL STREAM FLOW RATE   0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0   BTU/LB

HEAT TRANSFERED 0.1159E+08 BTU/HR

AREA REQUIRED   1651.61 SQR FT

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN *** OUTPUT LISTING ***

HEAT EXCHANGER

ELEMENT NUMBER** 7

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	23	13	29	14
FLOW RATE,LB/HR	356335.00	5190.00	356335.00	5190.00
TEMPERATURE,DEG F	94.00	306.00	160.00	170.05
HEAT CAPACITY,BTU/LB F	0.49300	16.43300	0.49300	16.43300
FLOW RATE STD,LB/HR	17816.75	259.50	0.0	0.0
TEMPERATURE STD,DEG F	0.94	3.06	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	450.00000	22.50000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	295.00000	14.75000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00375	0.00019
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00160	0.00008
OVERALL COEFF.,BTU/SQR FT HR DEG F	77.12622	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.1159E+08 BTU/HR

AREA REQUIRED 1651.61 SQR FT

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN *** OUTPUT LISTING ***

STREAM DIVIDER

ELEMENT NUMBER** 9

NUMBER OF FEED STREAMS** 1 NUMBER OF PRODUCT STREAMS** 2

	FEED	PRODUCT			
STREAM NUMBER	18	19	21	0	0
FLOW RATE LB/HR	356335.00	178167.50	178167.50	0.0	0.0
TEMPERATURE,DEG F	160.00	160.00	160.00	0.0	0.0
HEAT CAPACITY,BTU/LB F	0.49300	0.49300	0.49300	0.0	0.0
FLOW RATE STD.LB/HR	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD.DEG F	0.0	0.0	0.0	0.0	0.0
HEAT CAPACITY STD.BTU/LB F	0.0	0.0	0.0	0.0	0.0

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN

*** OUTPUT LISTING ***

HEAT EXCHANGER

ELEMENT NUMBER** 10

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	19	2	20	3
FLOW RATE,LB/HR	178167.50	85655.00	178167.50	85655.00
TEMPERATURE,DEG F	160.00	284.00	253.00	251.00
HEAT CAPACITY,BTU/LB F	0.50200	2.94300	0.50200	2.94300
FLOW RATE STD,LB/HR	0.0	4282.75	0.0	0.0
TEMPERATURE STD,DEG F	0.0	2.84	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	460.00000	23.00000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	150.00000	7.50000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00423	0.00021
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00300	0.00015
OVERALL COEFF.,BTU/SQR FT HR DEG F	54.96185	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 2

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.8313E+07 BTU/HR

AREA REQUIRED 2839.12 SQR FT

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN *** OUTPUT LISTING ***

HEAT EXCHANGER

ELEMENT NUMBER** 11

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	21	3	22	4
FLOW RATE,LB/HR	178167.50	85655.00	178167.50	85655.00
TEMPERATURE,DEG F	150.00	251.00	203.00	234.00
HEAT CAPACITY,BTU/LB F	0.50200	2.64120	0.50200	2.64120
FLOW RATE STD,LB/HR	0.0	0.0	0.0	0.0
TEMPERATURE STD,DEG F	0.0	0.0	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	460.00000	23.00000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	140.00000	7.00000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00450	0.00023
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00320	0.00016
OVERALL COEFF.,BTU/SQR FT HR DEG F	52.04057	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.3846E+07 BTU/HR

AREA REQUIRED 1275.02 SQR FT

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN *** OUTPUT LISTING ***

STREAM DIVIDER

ELEMENT NUMBER** 12

NUMBER OF FEED STREAMS** 1 NUMBER OF PRODUCT STREAMS** 2

	FEED	PRODUCT			
STREAM NUMBER	29	24	26	0	0
FLOW RATE LB/HR	356335.00	178167.50	178167.50	0.0	0.0
TEMPERATURE,DEG F	160.00	160.00	160.00	0.0	0.0
HEAT CAPACITY,BTU/LB F	0.49300	0.49300	0.49300	0.0	0.0
FLOW RATE STD,LB/HR	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD,DEG F	0.0	0.0	0.0	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0	0.0

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN *** OUTPUT LISTING ***

HEAT EXCHANGER

ELEMENT NUMBER** 13

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	24	5	25	6
FLOW RATE,LB/HR	178167.50	85655.00	178167.50	85655.00
TEMPERATURE,DEG F	160.00	284.00	253.00	251.00
HEAT CAPACITY,BTU/LB F	0.50200	2.94300	0.50200	2.94300
FLOW RATE STD,LB/HR	0.0	4282.75	0.0	0.0
TEMPERATURE STD,DEG F	0.0	2.84	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	460.00000	23.00000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	150.00000	7.50000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00423	0.00021
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00300	0.00015
OVERALL COEFF.,BTU/SQR FT HR DEG F	54.96185	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20490	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 2

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.8318E+07 BTU/HR

AREA REQUIRED 2839.12 SQR FT

HEAT EXCHANGER

ELEMENT NUMBER** 14

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	26	5	27	7
FLOW RATE,LB/HR	178167.50	85655.00	178167.50	85655.00
TEMPERATURE,DEG F	160.00	251.00	203.00	234.00
HEAT CAPACITY,BTU/LB F	0.50200	2.64120	0.50200	2.64120
FLOW RATE STD,LB/HR	0.0	0.0	0.0	0.0
TEMPERATURE STD,DEG F	0.0	0.0	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	460.00000	23.00000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	140.00000	7.00000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00450	0.00023
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00320	0.00016
OVERALL COEFF.,BTU/SQR FT HR DEG F	52.04057	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.3846E+07 BTU/HR

AREA REQUIRED 1275.02 SQR FT

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN *** OUTPUT LISTING ***

STREAM ADDER

ELEMENT NUMBER** 8

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 1

	FEED				PRODUCT
STREAM NUMBER	12	14	0	0	15
FLOW RATE LB/HR	5190.00	5190.00	0.0	0.0	10380.00
TEMPERATURE DEG F	170.05	170.05	0.0	0.0	170.05
HEAT CAPACITY BTU/LB F	16.43300	16.43300	0.0	0.0	16.43298
FLOW RATE STD LB/HR	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD.DEG F	0.0	0.0	0.0	0.0	0.0
HEAT CAPACITY STD BTU/LB F	0.0	0.0	0.0	0.0	0.0

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN

*** OUTPUT LISTING ***

STREAM ADDER

ELEMENT NUMBER** 15

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 1

	FEED				PRODUCT
STREAM NUMBER	4	7	0	0	8
FLOW RATE LB/HR	85655.00	85655.00	0.0	0.0	171310.00
TEMPERATURE DEG F	234.00	234.00	0.0	0.0	234.00
HEAT CAPACITY BTU/LB F	2.64120	2.64120	0.0	0.0	2.64120
FLOW RATE STD LB/HR	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD.DEG F	0.0	0.0	0.0	0.0	0.0
HEAT CAPACITY STD BTU/LB F	0.0	0.0	0.0	0.0	0.0

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN *** OUTPUT LISTING ***

STREAM ADDER

ELEMENT NUMBER** 15

NUMBER OF FEED STREAMS** 4 NUMBER OF PRODUCT STREAMS** 1

	FEED				PRODUCT
STREAM NUMBER	20	22	25	27	28
FLOW RATE LB/HR	178167.50	178167.50	178167.50	178167.50	712670.00
TEMPERATURE DEG F	253.00	203.00	253.00	203.00	228.00
HEAT CAPACITY BTU/LB F	0.50200	0.50200	0.50200	0.50200	0.50200
FLOW RATE STD LB/HR	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD,DEG F	0.0	0.0	0.0	0.0	0.0
HEAT CAPACITY STD BTU/LB F	0.0	0.0	0.0	0.0	0.0

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN *** OUTPUT LISTING ***

HEAT EXCHANGER

ELEMENT NUMBER** 29

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	60	70	61	71
FLOW RATE,LB/HR	634300.00	91215.00	634300.00	91216.00
TEMPERATURE,DEG F	367.00	579.00	394.00	411.09
HEAT CAPACITY,BTU/LB F	0.62600	0.70000	0.62600	0.70000
FLOW RATE STD.LB/HR	31715.00	4560.60	0.0	0.0
TEMPERATURE STD,DEG F	3.67	5.79	0.0	0.0
HEAT CAPACITY STD.BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	385.00000	19.25000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	290.00000	14.50000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00246	0.00012
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00150	0.00008
OVERALL COEFF.,BTU/SQR FT HR DEG F	85.07179	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.1072E+08 BTU/HR

AREA REQUIRED 1416.31 SQR FT

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN *** OUTPUT LISTING ***

STREAM DIVIDER

ELEMENT NUMBER** 30

NUMBER OF FEED STREAMS** 1 NUMBER OF PRODUCT STREAMS** 2

	FEED	PRODUCT			
STREAM NUMBER	61	62	63	0	0
FLOW RATE LB/HR	634300.00	317150.00	317150.00	0.0	0.0
TEMPERATURE.DEG F	394.00	394.00	394.00	0.0	0.0
HEAT CAPACITY.BTU/LB F	0.62600	0.62600	0.62600	0.0	0.0
FLOW RATE STD.LB/HR	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD.DEG F	0.0	0.0	0.0	0.0	0.0
HEAT CAPACITY STD.BTU/LB F	0.0	0.0	0.0	0.0	0.0

HEAT EXCHANGER

ELEMENT NUMBER** 32

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	62	75	65	76
FLOW RATE,LB/HR	317150.00	144039.00	317150.00	144039.00
TEMPERATURE,DEG F	394.00	631.00	460.00	550.10
HEAT CAPACITY,BTU/LB F	0.66800	1.20000	0.66800	1.20000
FLOW RATE STD,LB/HR	0.0	7201.95	0.0	0.0
TEMPERATURE STD,DEG F	0.0	6.31	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	200.00000	10.00000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	142.89999	7.15000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00270	0.00013
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00100	0.00005
OVERALL COEFF.,BTU/SQR FT HR DEG F	54.59800	0.0
TUBE WALL THERMAL CONDTY.BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.1398E+08 BTU/HR

AREA REQUIRED 1610.74 SQR FT

HEAT EXCHANGER

ELEMENT NUMBER** 31

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	63	76	64	77
FLOW RATE,LB/HR	317150.00	144039.00	317150.00	144039.00
TEMPERATURE,DEG F	394.00	550.10	460.00	469.21
HEAT CAPACITY,BTU/LB F	0.66800	1.20000	0.66800	1.20000
FLOW RATE STD,LB/HR	0.0	0.0	0.0	0.0
TEMPERATURE STD,DEG F	0.0	0.0	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	200.00000	10.00000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	181.80000	9.10000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00270	0.00013
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00100	0.00005
OVERALL COEFF.,BTU/SQR FT HR DEG F	59.93361	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.1398E+08 BTU/HR

AREA REQUIRED 3325.04 SQR FT

STREAM ADDER

ELEMENT NUMBER** 33

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 1

	FEED				PRODUCT
STREAM NUMBER	64	65	0	0	66
FLOW RATE LB/HR	317150.00	317150.00	0.0	0.0	634300.00
TEMPERATURE DEG F	460.00	460.00	0.0	0.0	460.00
HEAT CAPACITY BTU/LB F	0.66800	0.66800	0.0	0.0	0.66800
FLOW RATE STD LB/HR	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD,DEG F	0.0	0.0	0.0	0.0	0.0
HEAT CAPACITY STD BTU/LB F	0.0	0.0	0.0	0.0	0.0

HEAT EXCHANGER

ELEMENT NUMBER** 34

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	66	80	67	81
FLOW RATE,LB/HR	634300.00	86166.00	634300.00	86166.00
TEMPERATURE,DEG F	460.00	642.00	476.90	522.70
HEAT CAPACITY,BTU/LB F	0.70000	0.73000	0.70000	0.73000
FLOW RATE STD,LB/HR	0.0	4308.30	0.0	0.0
TEMPERATURE STD,DEG F	0.0	6.42	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	327.00000	16.35001
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	380.00000	19.00000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00200	0.00010
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00166	0.00008
OVERALL COEFF.,BTU/SQR FT HR DEG F	90.09842	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.7504E+07 BTU/HR

AREA REQUIRED 813.77 SQR FT

HEAT EXCHANGER

ELEMENT NUMBER** 17

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	30	71	31	72
FLOW RATE,LB/HR	712670.00	91216.00	712670.00	91216.00
TEMPERATURE,DEG F	226.00	411.09	249.70	255.13
HEAT CAPACITY,BTU/LB F	0.55000	0.65300	0.55000	0.65300
FLOW RATE STD,LB/HR	35633.50	0.0	0.0	0.0
TEMPERATURE STD,DEG F	2.26	0.0	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	150.00000	8.00000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	120.00000	6.00000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00780	0.00039
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00550	0.00028
OVERALL COEFF.,BTU/SQR FT HR DEG F	31.11947	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT   PAR-CNTR

NUMBER OF SHELL-PASSES   2

ISOTHERMAL STREAM FLOW RATE   0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0   BTU/LB

HEAT TRANSFERED 0.9290E+07 BTU/HR

AREA REQUIRED   3972.80 SQR FT

STREAM DIVIDER

ELEMENT NUMBER** 18

NUMBER OF FEED STREAMS** 1 NUMBER OF PRODUCT STREAMS** 2

	FEED	PRODUCT			
STREAM NUMBER	31	32	34	0	0
FLOW RATE LB/HR	712670.00	356335.00	356335.00	0.0	0.0
TEMPERATURE,DEG F	249.70	249.70	249.70	0.0	0.0
HEAT CAPACITY,BTU/LB F	0.55000	0.55000	0.55000	0.0	0.0
FLOW RATE STD,LB/HR	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD,DEG F	0.0	0.0	0.0	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0	0.0

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN *** OUTPUT LISTING ***

HEAT EXCHANGER

ELEMENT NUMBER** 20

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	34	45	35	46
FLOW RATE,LB/HR	356335.00	69062.00	356335.00	69062.00
TEMPERATURE,DEG F	249.70	413.00	274.70	301.00
HEAT CAPACITY,BTU/LB F	0.58000	0.66800	0.58000	0.66800
FLOW RATE STD,LB/HR	0.0	3453.10	0.0	0.0
TEMPERATURE STD,DEG F	0.0	4.13	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	222.20000	11.11000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	192.30000	9.62000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00300	0.00015
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00160	0.00009
OVERALL COEFF.,BTU/SQR FT HR DEG F	59.77394	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.5167E+07 BTU/HR

AREA REQUIRED 1056.63 SQR FT

HEAT EXCHANGER

ELEMENT NUMBER** 19

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	32	46	33	47
FLOW RATE,LB/HR	356335.00	69052.00	356335.00	69062.00
TEMPERATURE,DEG F	249.70	301.00	256.70	267.01
HEAT CAPACITY,BTU/LB F	0.56000	0.59500	0.56000	0.59500
FLOW RATE STD,LB/HR	0.0	0.0	0.0	0.0
TEMPERATURE STD,DEG F	0.0	0.0	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	200.00000	10.00000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	154.00000	7.70000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00400	0.00020
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00300	0.00015
OVERALL COEFF.,BTU/SQR FT HR DEG F	45.86057	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.1397E+07 BTU/HR

AREA REQUIRED 1095.34 SQR FT

STREAM ADDER

ELEMENT NUMBER** 21

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 1

	FEED				PRODUCT
STREAM NUMBER	33	35	0	0	36
FLOW RATE LB/HR	356335.00	356335.00	0.0	0.0	712670.00
TEMPERATURE DEG F	256.70	274.70	0.0	0.0	265.70
HEAT CAPACITY BTU/LB F	0.56000	0.58000	0.0	0.0	0.57000
FLOW RATE STD LB/HR	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD.DEG F	0.0	0.0	0.0	0.0	0.0
HEAT CAPACITY STD BTU/LB F	0.0	0.0	0.0	0.0	0.0

HEAT EXCHANGER

ELEMENT NUMBER** 22

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	36	77	37	78
FLOW RATE,LB/HR	712670.00	144039.00	712670.00	144039.00
TEMPERATURE,DEG F	265.70	469.21	302.60	307.63
HEAT CAPACITY,BTU/LB F	0.58500	0.66100	0.58500	0.66100
FLOW RATE STD,LB/HR	0.0	0.0	0.0	0.0
TEMPERATURE STD,DEG F	0.0	0.0	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	333.33008	16.57000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	285.69995	14.29000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00250	0.00013
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00163	0.00008
OVERALL COEFF.,BTU/SQR FT HR DEG F	79.98405	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.1538E+08 BTU/HR

AREA REQUIRED 2516.64 SQR FT

PROBLEM IDENTIFICATION***CRUDE PREHEAT TRAIN *** OUTPUT LISTING ***

STREAM DIVIDER

ELEMENT NUMBER** 23

NUMBER OF FEED STREAMS** 1 NUMBER OF PRODUCT STREAMS** 2

	FEED	PRODUCT			
STREAM NUMBER	37	38	40	0	0
FLOW RATE LB/HR	712670.00	356335.00	356335.00	0.0	0.0
TEMPERATURE,DEG F	302.60	302.60	302.60	0.0	0.0
HEAT CAPACITY,BTU/LB F	0.58500	0.58500	0.58500	0.0	0.0
FLOW RATE STD,LB/HR	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD,DEG F	0.0	0.0	0.0	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0	0.0

HEAT EXCHANGER

ELEMENT NUMBER** 25

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	40	50	41	51
FLOW RATE,LB/HR	356335.00	94220.00	356335.00	94220.00
TEMPERATURE,DEG F	302.60	491.00	339.50	363.55
HEAT CAPACITY,BTU/LB F	0.60000	0.65700	0.60000	0.65700
FLOW RATE STD,LB/HR	0.0	4711.00	0.0	0.0
TEMPERATURE STD,DEG F	0.0	4.91	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	284.00000	14.20000
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	196.00000	9.80000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00500	0.00025
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00470	0.00023
OVERALL COEFF.,BTU/SQR FT HR DEG F	47.53691	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.7889E+07 BTU/HR

AREA REQUIRED 1832.14 SQR FT

HEAT EXCHANGER

ELEMENT NUMBER** 24

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	38	51	39	52
FLOW RATE,LB/HR	356335.00	94220.00	356335.00	94220.00
TEMPERATURE,DEG F	302.60	363.55	312.20	328.32
HEAT CAPACITY,BTU/LB F	0.59400	0.61200	0.59400	0.61200
FLOW RATE STD,LB/HR	0.0	0.0	0.0	0.0
TEMPERATURE STD,DEG F	0.0	0.0	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	312.50000	15.62500
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	357.10010	17.86000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00206	0.00010
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00180	0.00009
OVERALL COEFF.,BTU/SQR FT HR DEG F	65.72052	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 1

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.2032E+07 BTU/HR

AREA REQUIRED 668.60 SQR FT

STREAM ADDER

ELEMENT NUMBER** 26

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 1

	FEED				PRODUCT
STREAM NUMBER	39	41	0	0	42
FLOW RATE LB/HR	356335.00	356335.00	0.0	0.0	712670.00
TEMPERATURE DEG F	312.20	339.50	0.0	0.0	325.85
HEAT CAPACITY BTU/LB F	0.59400	0.60000	0.0	0.0	0.59700
FLOW RATE STD LB/HR	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD.DEG F	0.0	0.0	0.0	0.0	0.0
HEAT CAPACITY STD BTU/LB F	0.0	0.0	0.0	0.0	0.0

HEAT EXCHANGER

ELEMENT NUMBER** 27

NUMBER OF FEED STREAMS** 2 NUMBER OF PRODUCT STREAMS** 2

	FEED		PRODUCT	
STREAM NUMBER	42	55	43	56
FLOW RATE,LB/HR	712670.00	361150.00	712670.00	361150.00
TEMPERATURE,DEG F	325.85	509.00	384.90	405.95
HEAT CAPACITY,BTU/LB F	0.56600	0.64000	0.56600	0.64000
FLOW RATE STD,LB/HR	0.0	18057.50	0.0	0.0
TEMPERATURE STD,DEG F	0.0	5.09	0.0	0.0
HEAT CAPACITY STD,BTU/LB F	0.0	0.0	0.0	0.0

HEAT EXCHANGER DATA

	NOMINAL VALUE	STD
INSIDE COEFF.,BTU/SQR FT HR DEG F	413.00000	20.64999
OUTSIDE COEFF.,BTU/SQR FT HR DEG F	600.00000	30.00000
INSIDE FOULING FACTR,SQR FT HR DEGF/BTU	0.00150	0.00008
OUTSIDE FOULING FACTR,SQR FT HR DEG F/BTU	0.00066	0.00003
OVERALL COEFF.,BTU/SQR FT HR DEG F	130.19350	0.0
TUBE WALL THERMAL CONDTY,BTU/FT HR DEG F	30.00000	
TUBE INSIDE WALL AREA SQRFT/FT	0.20480	
TUBE OUTSIDE WALL AREA SQRFT/FT	0.26180	

FLOW ARRANGEMENT PAR-CNTR

NUMBER OF SHELL-PASSES 2

ISOTHERMAL STREAM FLOW RATE 0.0 LB/HR

ISOTHERMAL STREAM ENTHALPY 0.0 BTU/LB

HEAT TRANSFERED 0.2382E+08 BTU/HR

AREA REQUIRED 1868.45 SQR FT

OUTPUT TANK

ELEMENT NUMBER** 35

NUMBER OF FEED STREAMS** 11 NUMBER OF PRODUCT STREAMS** 0

FEED

STREAM NUMBER	28	8	15	72	47	78	52	56	43	81
FLOW RATE LB/HR	712670.00	171310.00	10380.00	91216.00	69062.00	144039.00	94220.00	361150.00	712670.00	86166.00
TEMPERATURE DEG F	228.00	234.00	170.05	255.13	267.01	307.63	328.32	405.95	384.90	522.70
HEAT CAPACITY BTU/LB F	0.53200	2.64120	16.43298	0.65300	0.59500	0.66100	0.61200	0.64000	0.56600	0.73000
FLOW RATE STD LB/HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TEMPERATURE STD DEG F	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEAT CPY STD BTU/LB F	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

STREAM NUMBER	67
FLOW RATE LB/HR	634300.00
TEMPERATURE DEG F	476.90
HEAT CAPACITY BTU/LB F	0.70000
FLOW RATE STD LB/HR	0.0
TEMPERATURE STD DEG F	0.0
HEAT CPY STD BTU/LB F	0.0

PROBLEM IDENTIFICATION***   PREHEAT TRAIN   *** OUTPUT LISTING ***

```
ELEMENT NUMBER**  6

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET**  1
MEAN AREA FOR THE REMAINING SIMULATICNS**  1733.760 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**   341.597 SQR FT


ELEMENT NUMBER**  7

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET**  1
MEAN AREA FOR THE REMAINING SIMULATICNS**  1738.120 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**   345.348 SQR FT


ELEMENT NUMBER** 10

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET**  0
MEAN AREA FOR THE REMAINING SIMULATICNS**  2876.666 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**   263.492 SQR FT


ELEMENT NUMBER** 11

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET**  0
MEAN AREA FOR THE REMAINING SIMULATICNS**  1297.577 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**   151.430 SQR FT


ELEMENT NUMBER** 13

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET**  0
MEAN AREA FOR THE REMAINING SIMULATICNS**  2866.765 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**   271.916 SQR FT
```

ELEMENT NUMBER** 14

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED** 0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET** 0
MEAN AREA FOR THE REMAINING SIMULATIONS** 1297.369 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS** 150.562 SQR FT

ELEMENT NUMBER** 29

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED** 0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET** 56
MEAN AREA FOR THE REMAINING SIMULATIONS** 1477.141 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS** 652.860 SQR FT

ELEMENT NUMBER** 32

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED** 0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET** 0
MEAN AREA FOR THE REMAINING SIMULATIONS** 1621.165 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS** 134.784 SQR FT

ELEMENT NUMBER** 31

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED** 0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET** 3
MEAN AREA FOR THE REMAINING SIMULATIONS** 3519.823 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS** 959.525 SQR FT

ELEMENT NUMBER** 34

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED** 0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET** 0
MEAN AREA FOR THE REMAINING SIMULATIONS** 824.835 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS** 109.480 SQR FT

```
ELEMENT NUMBER** 17

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET**148
MEAN AREA FOR THE REMAINING SIMULATIONS**  3362.662 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**  1052.395 SQR FT



ELEMENT NUMBER** 20

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET**  0
MEAN AREA FOR THE REMAINING SIMULATIONS**  1075.314 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**   149.122 SQR FT



ELEMENT NUMBER** 19

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET** 56
MEAN AREA FOR THE REMAINING SIMULATIONS**  1175.106 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**   535.302 SQR FT



ELEMENT NUMBER** 22

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET** 69
MEAN AREA FOR THE REMAINING SIMULATIONS**  2554.318 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**   860.071 SQR FT



ELEMENT NUMBER** 25

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET**  0
MEAN AREA FOR THE REMAINING SIMULATIONS**  1884.039 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**   292.771 SQR FT
```

```
ELEMENT NUMBER** 24

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET** 29
MEAN AREA FOR THE REMAINING SIMULATIONS**    760.732 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**    379.575 SQR FT


ELEMENT NUMBER** 27

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET**  0
MEAN AREA FOR THE REMAINING SIMULATIONS**  1899.567 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**    218.071 SQR FT
```

APPENDIX D

PART OF THE RESULTS OF THE AREA CALCULATION OF THE CRUDE PREHEAT TRAIN FOR THE CASE OF 1% AND 5% COEFFICIENTS OF VARIATION

```
PROBLEM IDENTIFICATION***       PREHEAT TRAIN                                    *** OUTPUT LISTING ***


ELEMENT NUMBER**  6

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET** 67
MEAN AREA FOR THE REMAINING SIMULATIONS**  1774.608 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**   743.256 SQR FT


ELEMENT NUMBER**  7

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET** 67
MEAN AREA FOR THE REMAINING SIMULATIONS**  1781.471 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**   742.162 SQR FT


ELEMENT NUMBER** 10

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET**115
MEAN AREA FOR THE REMAINING SIMULATIONS**  2693.821 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**   619.050 SQR FT


ELEMENT NUMBER** 11

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET**  4
MEAN AREA FOR THE REMAINING SIMULATIONS**  1482.068 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**   763.129 SQR FT


ELEMENT NUMBER** 13

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET**115
MEAN AREA FOR THE REMAINING SIMULATIONS**  2672.297 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**   630.487 SQR FT
```

```
ELEMENT NUMBER** 14

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET**  4
MEAN AREA FOR THE REMAINING SIMULATIONS**  1484.085 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**   778.707 SQR FT


ELEMENT NUMBER** 29

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED** 36
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET**189
MEAN AREA FOR THE REMAINING SIMULATIONS**   940.319 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**   811.875 SQR FT


ELEMENT NUMBER** 32

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET**  1
MEAN AREA FOR THE REMAINING SIMULATIONS**  1731.052 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**   512.562 SQR FT


ELEMENT NUMBER** 31

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET**112
MEAN AREA FOR THE REMAINING SIMULATIONS**  3285.611 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**  1763.203 SQR FT


ELEMENT NUMBER** 34

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET** 32
MEAN AREA FOR THE REMAINING SIMULATIONS**   909.510 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**   453.435 SQR FT
```

```
ELEMENT NUMBER** 17

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  8
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET**210
MEAN AREA FOR THE REMAINING SIMULATIONS**  1801.689 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**  1367.325 SQR FT


ELEMENT NUMBER** 20

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET** 30
MEAN AREA FOR THE REMAINING SIMULATIONS**  1154.127 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**   513.133 SQR FT


ELEMENT NUMBER** 19

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET**153
MEAN AREA FOR THE REMAINING SIMULATIONS**   958.088 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**   619.386 SQR FT


ELEMENT NUMBER** 22

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET**157
MEAN AREA FOR THE REMAINING SIMULATIONS**  2185.177 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**  1090.763 SQR FT


ELEMENT NUMBER** 25

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET** 46
MEAN AREA FOR THE REMAINING SIMULATIONS**  2047.865 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**   932.166 SQR FT
```

```
ELEMENT NUMBER** 24

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET**142
MEAN AREA FOR THE REMAINING SIMULATIONS**   683.624 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**   510.652 SQR FT


ELEMENT NUMBER** 27

TOTAL NUMBER OF SIMULATIONS**500
NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEEDED**  0
NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS CAN NOT BE MET** 41
MEAN AREA FOR THE REMAINING SIMULATIONS**  1949.298 SQR FT
STANDARD DEVIATION FOR THE REMAINING SIMULATIONS**   583.352 SQR FT
```

APPENDIX E

80/80 LISTING OF THE COMPUTER PROGRAM

```
C                                                                       MAIN0010
C     THIS COMPUTER PROGRAM SIMULATES SHELL AND TUBE HEAT EXCHANGERS    MAIN0020
C     SYSTEMS AND CALCULATE THE PERFORMANCE WHEN UNCERTAINTIES EXIST    MAIN0030
C     USING THE MONTE CARLO TECHNIQUE.                                  MAIN0040
C                                                                       MAIN0050
      DIMENSION TMEAN(20),STAND(20),TAV(100),LIST(100),WAV(100),        MAIN0060
     $ITER(100)                                                         MAIN0080
      REAL KW(100)                                                      MAIN0090
      COMMON//ID(18)                                                    MAIN0100
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(MAIN0110
     $100),LUNIT(100),PUNIT(2)                                          MAIN0120
      COMMON/ARAV/AREA(100,500),ANL(100),IREA(100),NUD(100),NQ(100),INFNMAIN0130
     1A(100),IZERA(100)                                                 MAIN0140
      COMMON/ZAK/IA,TBAR,STDV,RVAR(9)                                   MAIN0150
      COMMON/ADTP/CPC(200),CPH(200),SCPC(200),SCPH(200),NFA(200),NSP(200MAIN0160
     1)                                                                 MAIN0170
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),MAIN0180
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1MAIN0190
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW                  MAIN0200
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SRMAIN0210
     1FO(100),SUD(100)                                                  MAIN0220
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX        MAIN0230
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20)               MAIN0240
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH                                   MAIN0250
      COMMON/TCPP/XAR(100),YAR(100),LIMIT,TMINV,IY,TINC                 MAIN0260
      COMMON/VAMXN/WMAX(20),WMIN(20),TMAX(20),TMIN(20),WOPT(20,500),TOPTMAIN0270
     $(20,500)                                                          MAIN0280
      COMMON/MEAN/HIM(100),HOM(100),RFIM(100),RFOM(100),WM(200),TM(200) MAIN0290
     1,CPM(200),UMD(100)                                                MAIN0300
      COMMON//PERCT(100,4)                                              MAIN0310
      COMMON/GUNIT/IUNIGH,NCASE,NYORD                                   MAIN0320
      COMMON//IXX                                                       MAIN0330
      DATA IBK/'    '/                                                  MAIN0340
      DATA TMEAN,STAND/20*0.0,20*0.0/                                   MAIN0345
C                                                                       MAIN0350
C     INITIALIZE VARIABLES                                              MAIN0360
C                                                                       MAIN0370
      NPRB=0                                                            MAIN0375
      NYORD=0                                                           MAIN0376
      IXX=0                                                             MAIN0380
      TINC=0.0                                                          MAIN0390
      DO 10 I=1,18                                                      MAIN0400
   10 ID(I)=IBK                                                         MAIN0410
      DO 60 INT=1,200                                                   MAIN0420
      W(INT)=0.0                                                        MAIN0430
      T(INT)=0.0                                                        MAIN0440
      CP(INT)=0.0                                                       MAIN0450
      SW(INT)=0.0                                                       MAIN0460
      ST(INT)=0.0                                                       MAIN0470
      SCP(INT)=0.0                                                      MAIN0480
   60 CONTINUE                                                          MAIN0490
      DO 65 IHX=1,100                                                   MAIN0500
      AI(IHX)=0.0                                                       MAIN0510
      AO(IHX)=0.0                                                       MAIN0520
      KW(IHX)=0.0                                                       MAIN0530
      IREA(IHX)=0                                                       MAIN0540
      INFNA(IHX)=0                                                      MAIN0550
      IZERA(IHX)=0                                                      MAIN0560
      NUD(IHX)=0                                                        MAIN0570
      NQ(IHX)=0                                                         MAIN0580
      NF(IHX)=0                                                         MAIN0590
      NP(IHX)=0                                                         MAIN0600
      TP1(IHX)=0.0                                                      MAIN0610
      TP2(IHX)=0.0                                                      MAIN0620
      CPC(IHX)=0.0                                                      MAIN0630
      CPH(IHX)=0.0                                                      MAIN0640
      ANL(IHX)=0.0                                                      MAIN0650
      A(IHX)=0.0                                                        MAIN0660
      DO 66 I=1,20                                                      MAIN0670
      IFD(IHX,I)=0                                                      MAIN0680
   66 IPD(IHX,I)=0                                                      MAIN0690
   65 CONTINUE                                                          MAIN0700
      DO 70 I=1,100                                                     MAIN0710
      DO 67 N=1,500                                                     MAIN0720
   67 AREA(I,N)=0.0                                                     MAIN0730
   70 CONTINUE                                                          MAIN0740
      NETRN=0                                                           MAIN0750
      NXX=0                                                             MAIN0760
C                                                                       MAIN0770
C     READ INPUT                                                        MAIN0780
C                                                                       MAIN0790
      READ(NREAD,11)ID                                                  MAIN0800
   11 FORMAT(18A4)                                                      MAIN0810
      READ(NREAD,15)NELMT,ISC,LX,JX,NPRB,NYORD,TINC                     MAIN0830
   15 FORMAT(3(6X,I4),1X,I9,2(6X,I4),F10.5)                             MAIN0840
      DO 100 I=1,NELMT                                                  MAIN0860
      READ(NREAD,5)JXX,NF(JXX),NP(JXX),KUNIT(JXX),LUNIT(JXX)            MAIN0870
    5 FORMAT(5(6X,I4))                                                  MAIN0880
      IF((NF(JXX).EQ.0).AND.(NP(JXX).GE.1))GO TO 20                     MAIN0890
      IF(((NF(JXX).GT.1).AND.(NF(JXX).LE.4)).AND.(NP(JXX).EQ.1))GO TO 35MAIN0900
      IF(((NP(JXX).GT.1).AND.(NP(JXX).LE.4)).AND.(NF(JXX).EQ.1))GO TO 40MAIN0910
      IF((NF(JXX).EQ.1).AND.(NP(JXX).EQ.1)) GO TO 45                    MAIN0920
      IF((NF(JXX).EQ.2).AND.(NP(JXX).EQ.2)) GO TO 45                    MAIN0930
      IF(NF(JXX).GE.1.AND.NP(JXX).EQ.0) GO TO 50                        MAIN0940
   20 CALL INPT(JXX)                                                    MAIN0950
      NELM(I)=JXX                                                       MAIN0960
      GO TO 100                                                         MAIN0970
   35 CALL ADDR(JXX)                                                    MAIN0980
      NELM(I)=JXX                                                       MAIN0990
      GO TO 100                                                         MAIN1000
   40 CALL DVDR(JXX)                                                    MAIN1010
      NELM(I)=JXX                                                       MAIN1020
      GO TO 100                                                         MAIN1030
```

```
   40 CALL HEXOO(JXX)
      NELM(I)=JXX
      GO TO 100
   50 CALL OTPT(JXX)
      NELM(I)=JXX
  100 CONTINUE
C
C     CONVERT UNITS AND CALCULATE UNKNOWN NOMINAL CONDITIONS FOR EACH
C     ELEMENT. PRINT RESULTS
C
      NETRN=1
      DO 295 NXX=1,2
      DO 290 NX=1,NELMT
      JXX=NELM(NX)
      IF(NF(JXX).EQ.0.AND.NP(JXX).GE.1)GO TO 212
      IF(NF(JXX).EQ.1.AND.NP(JXX).EQ.1) GO TO 202
      IF(NF(JXX).EQ.2.AND.NP(JXX).EQ.2) GO TO 203
      IF(NF(JXX).EQ.1.AND.NP(JXX).GT.1.AND.NP(JXX).LE.4)GO TO 204
      IF(NF(JXX).GT.1.AND.NF(JXX).LE.4.AND.NP(JXX).EQ.1) GO TO 206
      IF(NF(JXX).GE.1.AND.NF(JXX).LE.20.AND.NP(JXX).EQ.0) GO TO 205
      GO TO 290
  212 IF(NXX.EQ.1) CALL UNITS(JXX)
      GO TO 290
  202 IF(NXX.EQ.1) GO TO 215
      CALL HEXOO(JXX)
      GO TO 290
  215 CALL UNITS(JXX)
      CALL HRCR(JXX)
      GO TO 290
  203 IF(NXX.EQ.1) GO TO 217
      CALL HEXOO(JXX)
      GO TO 290
  217 CALL UNITS(JXX)
      CALL HEX(JXX)
      GO TO 290
  204 CALLDVDR(JXX)
      GO TO 290
  206 CALL ADDR(JXX)
      GO TO 290
  205 IF(NXX.EQ.1)GO TO 290
      CALL OTPT(JXX)
  290 CONTINUE
  295 CONTINUE
      IF(ISC.EQ.0) GO TO 1500
C
C     MONTE CARLO SIMULATION
C
      NETRN=2
  505 DO 2500 IPR=1,LX
      DO 2000 I=1,NELMT
      JXX=NELM(I)
      IF((NF(JXX).EQ.0).AND.(NP(JXX).GE.1))GO TO 310
      IF((NP(JXX).EQ.0).AND.(NF(JXX).GE.1))GO TO 320
      IF(NF(JXX).GT.1.AND.NF(JXX).LE.4.AND.NP(JXX).EQ.1) GO TO 330
      IF(NP(JXX).GT.1.AND.NP(JXX).LE.4.AND.NF(JXX).EQ.1) GO TO 340
      IF((NF(JXX).EQ.1).AND.(NP(JXX).EQ.1))GO TO 350
      IF((NF(JXX).EQ.2).AND.(NP(JXX).EQ.2))GO TO 360
  310 CALL PANDV(JXX)
      GO TO 2000
  330 CALL ADDR(JXX)
      GO TO 2000
  340 CALL DVDR(JXX)
      GO TO 2000
  350 CALL HRCR(JXX)
      IF(IERR(JXX).EQ.1) GO TO 1500
      GO TO 2000
  360 CALL HEX(JXX)
      IF(IERR(JXX).EQ.1) GO TO 1500
      GO TO 2000
  320 IF(IPR.GT.1) GO TO 370
      MOTPT=NF(JXX)
      DO 365 NK=1,MOTPT
      WMAX(NK)=0.000001
      WMIN(NK)=90000000.0
      TMAX(NK)=0.00001
      TMIN(NK)=100000000.0
  365 CONTINUE
  370 CALL PRINT(JXX)
 2000 CONTINUE
 2500 CONTINUE
C
C     CALCULATE THE MEAN AND STANDARD DEVIATION FOR EACH HEAT EXCHANGER
C     AREA
C
      MTEMP=0
      DO 400 I=1,NELMT
      JXX=NELM(I)
      IF(NF(JXX).EQ.1.AND.NP(JXX).EQ.1) GO TO 410
      IF(NF(JXX).EQ.2.AND.NP(JXX).EQ.2) GO TO 410
      GO TO 400
  410 IF(IREA(JXX).GE.1) CALL VAHX(JXX)
      IF(IREA(JXX).GE.1)MTEMP=1
  400 CONTINUE
      IF(MTEMP.GE.1) GO TO 1500
C
C     CALCULATE THE MEAN AND STANDARD DEVIATION FOR EACH OUTLET STREAM.
C
      JXX=NELM(NELMT)
      DO 1400 IY=1,MOTPT
      IA=IFD(JXX,IY)
      IF(TMAX(IY).EQ.TMIN(IY)) GO TO 1400
      IUNIGH=LUNIT(JXX)
      MK=TMIN(IY)/10.0
      AMK=MK*10
      IF(TINC.NE.0.0) GO TO 420
      TINC=1.0
  420 BMK=AMK-TINC/2.0
      INTLT=(TMAX(IY)-BMK)/TINC+0.5
```

```
      IF(INTLT.LE.100) GO TO 420                                        MAIN2120
      TINC=TINC+1.0                                                     MAIN2130
      GO TO 420                                                         MAIN2140
  420 DO 1420 NT=1,INTLT                                                MAIN2150
      YAR(NT)=0.0                                                       MAIN2160
      XAR(NT)=0.0                                                       MAIN2170
 1420 LIST(NT)=0                                                        MAIN2180
      SUMA=0.0                                                          MAIN2190
      SUMT1=0.0                                                         MAIN2200
      SUMT2=0.0                                                         MAIN2210
      SUMT3=0.0                                                         MAIN2220
      SUMT4=0.0                                                         MAIN2230
      DO 1450 IS=1,LX                                                   MAIN2240
      LT=(TOPT(IY,IS)-AMK)/TINC+1.0                                     MAIN2250
      LIST(LT)=LIST(LT)+1                                               MAIN2260
      SUMA=TOPT(IY,IS)+SUMA                                             MAIN2270
 1450 CONTINUE                                                          MAIN2280
      DO 1452 IT=1,INTLT                                                MAIN2290
      IM=IT-1                                                           MAIN2300
      TAV(IT)=AMK+IM*TINC                                               MAIN2310
 1452 CONTINUE                                                          MAIN2320
      LIMIT=INTLT                                                       MAIN2330
 1455 BLX=LX                                                            MAIN2340
      TPRB=0.0                                                          MAIN2350
      DO 1456 NX=1,LIMIT                                                MAIN2360
      ALIST=LIST(NX)                                                    MAIN2370
      TPRB=ALIST/BLX+TPRB                                               MAIN2380
      XAR(NX)=TAV(NX)                                                   MAIN2390
      YAR(NX)=TPRB                                                      MAIN2400
 1456 CONTINUE                                                          MAIN2410
C                                                                       MAIN2420
C     PLOT THE CUMULATIVE PROBABILITY CURVES                            MAIN2430
C                                                                       MAIN2440
      TMINN=AMK                                                         MAIN2450
      TBAR=SUMA/BLX                                                     MAIN2460
      TMEAN(IY)=TBAR                                                    MAIN2465
      DO 1440 IZ=1,LX                                                   MAIN2470
      T1=TOPT(IY,IZ)-TBAR                                               MAIN2480
      T2=T1*T1                                                          MAIN2490
      T3=T1*T1*T1                                                       MAIN2500
      T4=T1*T1*T1*T1                                                    MAIN2510
      SUMT1=T1+SUMT1                                                    MAIN2520
      SUMT2=T2+SUMT2                                                    MAIN2530
      SUMT3=T3+SUMT3                                                    MAIN2540
      SUMT4=T4+SUMT4                                                    MAIN2550
 1440 CONTINUE                                                          MAIN2560
      TMOM1=SUMT1/BLX                                                   MAIN2570
      TMOM2=SUMT2/BLX                                                   MAIN2580
      TMOM3=SUMT3/BLX                                                   MAIN2590
      TMOM4=SUMT4/BLX                                                   MAIN2600
      BT1=TMOM3/(TMOM2)**1.5                                            MAIN2610
      BT2=TMOM4/TMOM2                                                   MAIN2620
      STDV=SQRT(TMOM2)                                                  MAIN2630
      STAND(IY)=STDV                                                    MAIN2635
      IF(NPRB.NE.0) CALL GRAPH                                          MAIN2640
 1400 CONTINUE                                                          MAIN2650
      IF(NPRB.NE.0) GO TO 1500                                          MAIN2660
      WRITE(NPRNT,375)ID                                                MAIN2670
  375 FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',13A4,1X,'*** OUTPUT LISTMAIN2680
     1ING ***')                                                         MAIN2690
      JXX=NELM(NELMT)                                                   MAIN2700
      IUNIT=LUNIT(JXX)                                                  MAIN2710
      WRITE(NPRNT,1460)TUNIT(IUNIT),TUNIT(IUNIT)                        MAIN2720
 1460 FORMAT(////5X,'RESULTS OF TEMPERATURE CALCULATION FOR ALL OUTLET SMAIN2730
     1TREAMS'//5X,'STREAM NUMBER',5X,'MEAN TEMPERATURE DEG ',A2,5X,'STANMAIN2740
     2DARD DEVIATION DEG ',A2//)                                        MAIN2750
      DO 1430 I=1,MOTPT                                                 MAIN2760
      IOT=IFD(JXX,I)                                                    MAIN2770
      WRITE(NPRNT,1425)IOT,TMEAN(I),STAND(I)                            MAIN2780
 1425 FORMAT(10X,I3,15X,F10.3,15X,F10.3)                                MAIN2790
 1430 CONTINUE                                                          MAIN2795
 1500 STOP                                                              MAIN2800
      END                                                               MAIN2810
```

```
      BLOCK DATA                                                        BKDA0010
      COMMON/ZAK/IA,TBAR,STDV,RVAR(9)                                   BKDA0020
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH                                   BKDA0030
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(BKDA0040
     $100),LUNIT(100),PUNIT(2)                                          BKDA0050
      DATA RVAR/3HALL,2HT2,2HT1,2HW2,2HW1,2HHI,2HHO,3HRFI,3HRFO/        BKDA0060
      DATA WUNIT/2HLB,2HKG/                                             BKDA0070
      DATA TUNIT/1HF,1HK/                                               BKDA0080
      DATA TMUNIT/2HHR,2HHR/                                            BKDA0090
      DATA EUNIT/3HBTU,3H KJ/                                           BKDA0100
      DATA PUNIT/3HBTU,3H  W/                                           BKDA0110
      DATA ALGTH/2HFT,2H M/                                             BKDA0120
      DATA NREAD,NPRNT,NPNCH/5,6,7/                                     BKDA0130
      END                                                               BKDA0140
```

```
      SUBROUTINE INPT(JXX)                                              INPT0010
C                                                                       INPT0020
C     SUBROUTINE INPT READS INPUT CONDITIONS OF UP TO 20 FEED STREAMS ININPT0030
C     THE ORDER THEY HAVE BEEN ARRANGED.                                INPT0040
C                                                                       INPT0050
      DIMENSION F(50),E(50),CT(50),SF(50),SE(50),SCT(50)                INPT0060
      COMMON//ID(18)                                                    INPT0070
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX        INPT0080
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(INPT0090
     $100),LUNIT(100),PUNIT(2)                                          INPT0100
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH                                   INPT0110
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20)               INPT0120
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),U(100),HI(100),HO(100),INPT0130
```

```
1RFI(100),HFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
200),WISO(100),HFO(100),A(100),AI(100),AO(100),KW
 COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SR
1FO(100),SUO(100)
 DATA F,E,CT,SF,SE,SCT/50*0.0,50*0.0,50*0.0,50*0.0,50*0.0,50*0.0/
370 FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,2X,'*** INPUT LISTI
1NG ***')
 IF(NETRN.EQ.0)WRITE(NPRNT,370)ID
 MINPT=NP(JXX)
 DO 23 MM=1,MINPT
 READ(NREAD,24)ISTM,W(ISTM),T(ISTM),CP(ISTM),SW(ISTM),ST(ISTM),SCP(
1ISTM)
24 FORMAT(5X,I4,2F10.2,F10.5,2F10.2,F10.5)
 IPD(JXX,MM)=ISTM
 F(MM)=W(ISTM)
 E(MM)=T(ISTM)
 CT(MM)=CP(ISTM)
 SF(MM)=SW(ISTM)
 SE(MM)=ST(ISTM)
 SCT(MM)=SCP(ISTM)
23 CONTINUE
 WRITE(NPRNT,25)JXX,NF(JXX),NP(JXX)
25 FORMAT(////1X,'INPUT TANK'//1X,'ELEMENT NUMBER**',I3//1X,     'NUM
1BER OF FEED STREAMS**',I3,' NUMBER OF PRODUCT STREAMS**',I3/////
265X,'PRODUCT')
 J=1
 N=10
27 WRITE(NPRNT,30)(IPD(JXX,MM),MM=J,N)
30 FORMAT(//1X,'STREAM NUMBER',14X,I4,9(6X,I4))
 IUNIT=KUNIT(JXX)
 WRITE(NPRNT,31)WUNIT(IUNIT),TMUNIT(IUNIT),(F(MM),MM=J,N)
31 FORMAT(///1X,'FLOW RATE ',A2,'/',A3,8X,10F10.2)
 WRITE(NPRNT,32)TUNIT(IUNIT),(E(MM),MM=J,N)
32 FORMAT(1X,'TEMPERATURE DEG ',A1,7X,10F10.2)
 WRITE(NPRNT,33)EUNIT(IUNIT),WUNIT(IUNIT),TUNIT(IUNIT),(CT(MM),MM=J
1,N)
33 FORMAT(1X,'HEAT CAPACITY ',A3,'/',A2,' ',A1,3X,10F10.5)
 WRITE(NPRNT,34)WUNIT(IUNIT),TMUNIT(IUNIT),(SF(MM),MM=J,N)
34 FORMAT(1X,'FLOW RATE STD ',A2,'/',A3,4X,10F10.2)
 WRITE(NPRNT,35)TUNIT(IUNIT),(SE(MM),MM=J,N)
35 FORMAT(1X,'TEMPRATURE STD DEG ',A1,4X,10F10.2)
 WRITE(NPRNT,36)EUNIT(IUNIT),WUNIT(IUNIT),TUNIT(IUNIT),(SCT(MM),MM=
1J,N)
36 FORMAT(1X,'HEAT CPY STD ',A3,'/',A2,' ',A1,3X,10F10.5)
 IF(N.GT.10) GO TO 40
 IF(MINPT.LE.10) GO TO 40
 WRITE(NPRNT,38)
38 FORMAT(//////)
 J=11
 N=MINPT
 GO TO 27
40 RETURN
 END
```

```
      SUBROUTINE ADDP(JXX)
C
C     SUBROUTINE ADDP ADDS UP TO 4 STREAMS INTO ONE PRODUCT STREAM.
C
      REAL KW(100)
      COMMON//ID(18)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     1100),LUNIT(100),PUNIT(2)
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20)
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
     2200),WISO(100),HFO(100),A(100),AI(100),AO(100),KW
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SR
     1FO(100),SUO(100)
  370 FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,2X,'*** INPUT LISTI
     1NG ***')
  375 FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,1X,'*** OUTPUT LIST
     1ING ***')
      IF(NETRN.EQ.0)WRITE(NPRNT,370)ID
      IF(NETRN.EQ.1.AND.NXX.EQ.2)WRITE(NPRNT,375)ID
      IF(NETRN.NE.0) GO TO 108
      READ(NREAD,105)(IFD(JXX,K),K=1,4),IPD(JXX,1)
  105 FORMAT(5(6X,I4))
  108 IFD1=IFD(JXX,1)
      IFD2=IFD(JXX,2)
      IFD3=IFD(JXX,3)
      IFD4=IFD(JXX,4)
      IPD1=IPD(JXX,1)
      W3=0.0
      SW3=0.0
      W4=0.0
      SW4=0.0
      T3=0.0
      ST3=0.0
      T4=0.0
      ST4=0.0
      CP3=0.0
      SCP3=0.0
      CP4=0.0
      SCP4=0.0
      IF(IFD3.EQ.0) GO TO 113
      W3=W(IFD3)
      SW3=SW(IFD3)
      T3=T(IFD3)
      ST3=ST(IFD3)
      CP3=CP(IFD3)
      SCP3=SCP(IFD3)
      IF(IFD4.EQ.0) GO TO 113
      W4=W(IFD4)
```

```
      SW4=SW(IFD4)
      T4=T(IFD4)
      ST4=ST(IFD4)
      CP4=CP(IFD4)
      SCP4=SCP(IFD4)
113   W(IPD1)=W(IFD1)+W(IFD2)+W3+W4
      T(IPD1)=(T(IFD1)*W(IFD1)+T(IFD2)*W(IFD2)+T3*W3+T4*W4)/W(IPD1)
      CP(IPD1)=(W(IFD1)*CP(IFD1)+W(IFD2)*CP(IFD2)+W3*CP3+W4*CP4)/W(IPD1)
      SW(IPD1)=SQRT(SW(IFD1)**2+SW(IFD2)**2+SW3**2+SW4**2)
      ST(IPD1)=SQRT(((W(IFD1)/W(IPD1))*ST(IFD1))**2+((W(IFD2)/W(IPD1))*
     1ST(IFD2))**2+((W3/W(IPD1))*ST3)**2+((W4/W(IPD1))*ST4)**2)
      SCP(IPD1)=SQRT(((W(IFD1)/W(IPD1))*SCP(IFD1))**2+((W(IFD2)/W(IPD1))
     1*SCP(IFD2))**2+((W3/W(IPD1))*SCP3)**2+((W4/W(IPD1))*SCP4)**2)
      IF(NETRN.EQ.1.AND.NXX.EQ.1) GO TO 130
      IF(NETRN.EQ.2.AND.ISC.GE.1) GO TO 130
115   WRITE(NPRNT,100)JXX,NF(JXX),NP(JXX)
100   FORMAT(////5X,'STREAM ADDER'//5X,'ELEMENT NUMBER**',I3//5X,    'NU
     1MBER OF FEED STREAMS**',I3,' NUMBER OF PRODUCT STREAMS**',I3/////6
     22X,'FEED',30X,'PRODUCT')
      WRITE(NPRNT,110)(IFD(JXX,K),K=1,4),IPD(JXX,1)
110   FORMAT(//5X,'STREAM NUMBER',22X,4(6X,I4),16X,I4)
      IF(NETRN.EQ.1.AND.NXX.EQ.2)KUNIT(JXX)=LUNIT(JXX)
      IUNIT=KUNIT(JXX)
      WRITE(NPRNT,117)WUNIT(IUNIT),TMUNIT(IUNIT),W(IFD1),W(IFD2),W3,W4,
     1W(IPD1),TUNIT(IUNIT),T(IFD1),T(IFD2),T3,T4,T(IPD1),EUNIT(IUNIT),
     2WUNIT(IUNIT),TUNIT(IUNIT),CP(IFD1),CP(IFD2),CP3,CP4,CP(IPD1)
117   FORMAT(///5X,'FLOW RATE ',A2,'/',A2,24X,4F10.2,10X,F10.2/5X,'TEMPE
     1RATURE DEG ',A1,22X,4F10.2,10X,F10.2/5X,'HEAT CAPACITY ',A3,'/',A2
     2,' ',A1,17X,4F10.5,10X,F10.5)
      WRITE(NPRNT,120)WUNIT(IUNIT),TMUNIT(IUNIT),SW(IFD1),SW(IFD2),SW3,
     1SW4,SW(IPD1),TUNIT(IUNIT),ST(IFD1),ST(IFD2),ST3,ST4,ST(IPD1),EUNIT
     2(IUNIT),WUNIT(IUNIT),TUNIT(IUNIT),SCP(IFD1),SCP(IFD2),SCP3,SCP4,
     3SCP(IPD1)
120   FORMAT(5X,'FLOW RATE STD ',A2,'/',A2,20X,4F10.2,10X,F10.2/5X,'TEMP
     1ERATURE STD,DEG ',A1,18X,4F10.2,10X,F10.2/5X,'HEAT CAPACITY STD ',A
     2A3,'/',A2,' ',A1,13X,4F10.5,10X,F10.5)
130   RETURN
      END


      SUBROUTINE DVDR(JXX)
C
C     SUBROUTINE DVDR DIVIDES ONE STRAM INTO UP TO 4 PRODUCT STREAMS
C
      REAL KW(100)
      COMMON//ID(18)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPK,ISC,LX,JX
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     $100),LUNIT(100),PUNIT(2)
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20)
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),
     1FI(100),FO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SR
     1FO(100),SUD(100)
      COMMON//PERCT(100,4)
370   FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,2X,'*** INPUT LIST
     1ING ***')
375   FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,1X,'*** OUTPUT LIST
     1ING ***')
      IF(NETRN.EQ.0)WRITE(NPRNT,370)ID
      IF(NETRN.EQ.1.AND.NXX.EQ.2)WRITE(NPRNT,375)ID
      IF(NETRN.NE.0) GO TO 213
      READ(NREAD,212)IFD(JXX,1),(IPD(JXX,M),M=1,4),(PERCT(JXX,M),M=1,4)
212   FORMAT(5(6X,I4)/4F10.5)
213   LA=IPD(JXX,1)
      LB=IPD(JXX,2)
      LC=IPD(JXX,3)
      LD=IPD(JXX,4)
      LE=IFD(JXX,1)
      FR1=PERCT(JXX,1)
      FR2=PERCT(JXX,2)
      FR3=PERCT(JXX,3)
      FR4=PERCT(JXX,4)
      W(LA)=W(LE)*FR1
      CP(LA)=CP(LE)
      T(LA)=T(LE)
      W(LB)=W(LE)*FR2
      CP(LB)=CP(LE)
      T(LB)=T(LE)
      SW(LA)=FR1*SW(LE)
      SW(LB)=FR2*SW(LE)
      ST(LA)=ST(LE)
      ST(LB)=ST(LE)
      SCP(LA)=SCP(LE)
      SCP(LB)=SCP(LE)
      WP3=0.0
      WP4=0.0
      TP3=0.0
      TP4=0.0
      CPP3=0.0
      CPP4=0.0
      SWP3=0.0
      SWP4=0.0
      STP3=0.0
      STP4=0.0
      SCPP3=0.0
      SCPP4=0.0
      IF(LC.EQ.0) GO TO 215
      WP3=W(LE)*FR3
      TP3=T(LE)
      CPP3=CP(LE)
      SWP3=SW(LE)*FR3
      STP3=ST(LE)
      SCPP3=SCP(LE)
```

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      IF(IT.EQ.1) GO TO 215                                              DVDR0670
      WP4=W(LE)*F4                                                       DVDR0680
      TP4=T(LE)                                                          DVDR0690
      SWP4=SW(LE)*F4                                                     DVDR0700
      STP4=ST(LE)                                                        DVDR0710
      SCPP4=SCP(LE)                                                      DVDR0720
  215 IF(NETRN.EQ.1.AND.NXX.EQ.1) GO TO 250                              DVDR0730
      IF(ISC.GE.1.AND.NETRN.EQ.2) GO TO 250                              DVDR0740
      WRITE(NPRNT,200)JXX,NF(JXX),NP(JXX)                                DVDR0750
  200 FORMAT(////5X,'STREAM DIVIDER'//5X,'ELEMENT NUMBER**',I3//5X,     'DVDR0760
     1NUMBER OF FEED STREAMS**',I2,' NUMBER OF PRODUCT STREAMS**',I2////DVDR0770
     27,7X,'FEED',32X,'PRODUCT')                                         DVDR0780
      WRITE(NPRNT,210)IFD(JXX,1),(IPD(JXX,M),M=1,4)                      DVDR0790
  210 FORMAT(//5X,'STREAM NUMBER',29X,I3,10X,4(9X,I3))                   DVDR0800
      IF(NETRN.EQ.1.AND.NXX.EQ.2) KUNIT(JXX)=LUNIT(JXX)                  DVDR0810
      IUNIT=KUNIT(JXX)                                                   DVDR0820
      WRITE(NPRNT,220)WUNIT(IUNIT),TMUNIT(IUNIT),W(LE),W(LA),W(LB),WP3,WDVDR0830
     1P4,TUNIT(IUNIT),T(LE),T(LA),T(LB),TP3,TP4,EUNIT(IUNIT),WUNIT(IUNITDVDR0840
     2),TUNIT(IUNIT),CP(LE),CP(LA),CP(LB),CPP3,CPP4                      DVDR0850
  220 FORMAT(///5X,'FLOW RATE ',A2,'/',A2,24X,F10.2,6X,4(2X,F10.2)/5X,'TDVDR0860
     1EMPERATURE,DEG ',A1,22X,F10.2,8X,4(2X,F10.2)/5X,'HEAT CAPACITY,',ADVDR0870
     23,'/',A2,' ',A1,17X,F10.5,8X,4(2X,F10.5))                          DVDR0880
      WRITE(NPRNT,230)WUNIT(IUNIT),TMUNIT(IUNIT),SW(LE),SW(LA),SW(LB),SWDVDR0890
     1P3,SWP4,TUNIT(IUNIT),ST(LE),ST(LA),ST(LB),STP3,STP4,EUNIT(IUNIT),WDVDR0900
     2UNIT(IUNIT),TUNIT(IUNIT),SCP(LE),SCP(LA),SCP(LB),SCPP3,SCPP4       DVDR0910
  230 FORMAT(5X,'FLOW RATE STD,',A2,'/',A2,20X,F10.2,6X,4(2X,F10.2)/5X, DVDR0920
     1'TEMPERATURE STD,DEG ',A1,18X,F10.2,8X,4(2X,F10.2)/5X,'HEAT CAPACIDVDR0930
     2TY STD,',A3,'/',A2,' ',A1,13X,F10.5,8X,4(2X,F10.5))                DVDR0940
  250 RETURN                                                             DVDR0950
      END                                                                DVDR0960


      SUBROUTINE HEXOO(JXX)                                              HX000010
C                                                                        HX000020
C     SUBROUTINE HEXOO READS AND PRINTS INPUT CONDITIONS AND RESULTS OF HX000030
C     CALCULATIONS FOR HEAT EXCHANGERS AND HEATERS AND COOLERS ELEMENTS.HX000040
C                                                                        HX000050
      DIMENSION AFRGT(6),TBUNIT(2)                                       HX000060
      REAL KW(100)                                                       HX000070
      COMMON//ID(18)                                                     HX000080
      COMMON/KEYS/IEPR(100),NELM(100),NXX,NETRN,NY,IPR,ISC,LX,JX         HX000090
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(HX000100
     $100),LUNIT(100),PUNIT(2)                                           HX000110
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH                                    HX000120
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20)                HX000130
      COMMON/ADATA/W(200),T(200),CP(200),U(100),UD(100),HI(100),HO(100),HX000140
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1HX000150
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW                   HX000160
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SRHX000170
     1FO(100),SUD(100)                                                   HX000180
      COMMON/VAMXN/WMAX(20),WMIN(20),TMAX(20),TMIN(20),WOPT(20,500),TOPTHX000190
     $(20,500)                                                           HX000200
      COMMON/ADAP/CPC(200),CPH(200),SCPC(200),SCPH(200),NFA(200),NSP(200HX000210
     1)                                                                  HX000220
      DATA TBUNIT/' ',' '/                                               HX000230
      DATA ARFGT/'PARA','LLEL','COUN','TER ','PARA','CNTR'/              HX000240
  300 FORMAT(////5X,'HEATER OR CONDSR'//5X,'ELEMENT NUMBER**',I3//5X     HX000250
     1,'NUMBER OF FEED STREAMS**',I2,' NUMBER OF PRODUCT STREAMS**',I2//HX000260
     2//52X,'FEED',26X,'PRODUCT')                                        HX000270
  370 FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,2X,'*** INPUT LISTIHX000280
     1NG ***')                                                           HX000290
  375 FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,1X,'*** OUTPUT LISTHX000300
     1ING ***')                                                          HX000310
      IF(NETRN.EQ.0)WRITE(NPRNT,370)ID                                   HX000320
      IF(NETRN.EQ.1.AND.NXX.EQ.2)WRITE(NPRNT,375)ID                      HX000330
      WNF2=0.0                                                           HX000340
      TNF2=0.0                                                           HX000350
      CPNF2=0.0                                                          HX000360
      SWNF2=0.0                                                          HX000370
      STNF2=0.0                                                          HX000380
      SCPNF2=0.0                                                         HX000390
      WNP2=0.0                                                           HX000400
      TNP2=0.0                                                           HX000410
      CPNP2=0.0                                                          HX000420
      SWNP2=0.0                                                          HX000430
      STNP2=0.0                                                          HX000440
      SCPNP2=0.0                                                         HX000450
      IF(NETRN.NE.0) GO TO 297                                           HX000460
C                                                                        HX000470
C     READ INPUT                                                         HX000480
C                                                                        HX000490
      READ(NREAD,290)IFD(JXX,1),IFD(JXX,2),IPD(JXX,1),IPD(JXX,2),U(JXX),HX000500
     1A(JXX),UD(JXX),HI(JXX),HO(JXX),RFI(JXX),RFO(JXX),AI(JXX),AO(JXX), HX000510
     2TISO(JXX),WISO(JXX),HFG(JXX),TP1(JXX),TP2(JXX),CPC(JXX),CPH(JXX), HX000520
     3DI(JXX),DO(JXX),KW(JXX),NFA(JXX),NSP(JXX)                          HX000530
  290 FORMAT(4(6X,I4)/E10.3,4F10.2,2F10.5/2F10.5,F10.2,F10.2,E10.3,F10.2HX000540
     1,F10.2/2F10.5,2F10.5,F10.3,2(6X,I4))                               HX000550
      READ(NREAD,295)SUD(JXX),SHI(JXX),SHO(JXX),SRFI(JXX),SRFO(JXX),SCPCHX000560
     1(JXX),SCPH(JXX)                                                    HX000570
  295 FORMAT(3F10.2,4F10.5)                                              HX000580
  297 NF1=IFD(JXX,1)                                                     HX000590
      NF2=IFD(JXX,2)                                                     HX000600
      NP1=IPD(JXX,1)                                                     HX000610
      NP2=IPD(JXX,2)                                                     HX000620
      IF(TP1(JXX).NE.0.0)T(NP1)=TP1(JXX)                                 HX000630
      IF(CPC(JXX).NE.0.0)CP(NF1)=CPC(JXX)                                HX000640
      IF(SCPC(JXX).NE.0.0)SCP(NF1)=SCPC(JXX)                             HX000650
      IF(NETRN.EQ.1.AND.NXX.EQ.2) KUNIT(JXX)=LUNIT(JXX)                  HX000660
      W(NP1)=W(NF1)                                                      HX000670
      CP(NP1)=CP(NF1)                                                    HX000680
      SCP(NP1)=SCP(NF1)                                                  HX000690
      IF(NF2.EQ.0) GO TO 350                                             HX000700
      IF(TP2(JXX).NE.0.0)T(NP2)=TP2(JXX)                                 HX000710
      IF(CPH(JXX).NE.0.0)CP(NF2)=CPH(JXX)                                HX000720
      IF(SCPH(JXX).NE.0.0)SCP(NF2)=SCPH(JXX)                             HX000730
      W(NP2)=W(NF2)                                                      HX000740
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      CP(NP2)=CP(NF2)
      SCP(NP2)=SCP(NF2)
      WNF2=W(NF2)
      TNF2=T(NF2)
      CPNF2=CP(NF2)
      SWNF2=SW(NF2)
      STNF2=ST(NF2)
      SCPNF2=SCP(NF2)
      WNP2=W(NP2)
      TNP2=T(NP2)
      CPNP2=CP(NP2)
      SWNP2=SW(NP2)
      STNP2=ST(NP2)
      SCPNP2=SCP(NP2)
C
C     PRINT OUTPUT
C
      WRITE(NPRNT,305)JXX,NF(JXX),NP(JXX)
  305 FORMAT(////5X,'HEAT EXCHANGER '//5X,'ELEMENT NUMBER**',I3//5X
     1,'NUMBER OF FEED STREAMS**',I2,' NUMBER OF PRODUCT STREAMS**',I2//
     2///52X,'FEED',26X,'PRODUCT')
  350 IF(NF2.EQ.0) WRITE(NPRNT,300)JXX,NF(JXX),NP(JXX)
      WRITE(NPRNT,310)IFD(JXX,1),IFD(JXX,2),IPD(JXX,1),IPD(JXX,2)
  310 FORMAT(//5X,'STREAM NUMBER',29X,I3,9X,I3,17X,I3,8X,I3)
      IUNIT=KUNIT(JXX)
      WRITE(NPRNT,320)WUNIT(IUNIT),TMUNIT(IUNIT),W(NF1),WNF2,W(NP1),WNP2
     1,TUNIT(IUNIT),T(NF1),TNF2,T(NP1),TNP2,EUNIT(IUNIT),WUNIT(IUNIT),TU
     2NIT(IUNIT),CP(NF1),CPNF2,CP(NP1),CPNP2
  320 FORMAT(///5X,'FLOW RATE,',A2,'/',A2,22X,2(2X,F10.2),8X,2(2X,F10.2)
     1/5X,'TEMPERATURE,DEG ',A1,20X,2(2X,F10.2),8X,2(2X,F10.2)/5X,'HEAT
     2CAPACITY,',A3,'/',A2,' ',A1,15X,2(2X,F10.5),8X,2(2X,F10.5))
      WRITE(NPRNT,330)WUNIT(IUNIT),TMUNIT(IUNIT),SW(NF1),SWNF2,SW(NP1),SH
     1WNP2,TUNIT(IUNIT),ST(NF1),STNF2,ST(NP1),STNP2,EUNIT(IUNIT),WUNIT(I
     2UNIT),TUNIT(IUNIT),SCP(NF1),SCPNF2,SCP(NP1),SCPNP2
  330 FORMAT(5X,'FLOW RATE STD,',A2,'/',A2,18X,2(2X,F10.2),8X,2(2X,F10.2
     1)/5X,'TEMPERATURE STD,DEG ',A1,16X,2(2X,F10.2),8X,2(2X,F10.2)/5X,
     2'HEAT CAPACITY STD,',A3,'/',A2,' ',A1,11X,2(2X,F10.5),8X,2(2X,F10.
     35))
      IF(IUNIT.NE.2) GO TO 335
      IF(NETRN.EQ.0) GO TO 333
      Q(JXX)=Q(JXX)/3.6
      UD(JXX)=UD(JXX)/3.6
      HI(JXX)=HI(JXX)/3.6
      HO(JXX)=HO(JXX)/3.6
      SUD(JXX)=SUD(JXX)/3.6
      SHI(JXX)=SHI(JXX)/3.6
      SHO(JXX)=SHO(JXX)/3.6
      RFI(JXX)=RFI(JXX)*3.6
      SRFI(JXX)=SRFI(JXX)*3.6
      RFO(JXX)=RFO(JXX)*3.6
      SRFO(JXX)=SRFO(JXX)*3.6
      KW(JXX)=KW(JXX)/3.6
  333 WRITE(NPRNT,340)PUNIT(IUNIT),ALGTH(IUNIT),TBUNIT(IUNIT),TUNIT(IUNI
     1T),HI(JXX),SHI(JXX),PUNIT(IUNIT),ALGTH(IUNIT),TBUNIT(IUNIT),TUNIT(
     2IUNIT),HO(JXX),SHO(JXX),ALGTH(IUNIT),TBUNIT(IUNIT),TUNIT(IUNIT),PU
     3NIT(IUNIT),RFI(JXX),SRFI(JXX),ALGTH(IUNIT),TBUNIT(IUNIT),TUNIT(IUN
     4IT),PUNIT(IUNIT),RFO(JXX),SRFO(JXX),PUNIT(IUNIT),ALGTH(IUNIT),TBUN
     5IT(IUNIT),TUNIT(IUNIT),UD(JXX),SUD(JXX)
      WRITE(NPRNT,342)PUNIT(IUNIT),ALGTH(IUNIT),TBUNIT(IUNIT),TUNIT(IUNI
     1T),KW(JXX)
      GO TO 345
  335 WRITE(NPRNT,340)EUNIT(IUNIT),ALGTH(IUNIT),TMUNIT(IUNIT),TUNIT(IUNI
     1T),HI(JXX),SHI(JXX),EUNIT(IUNIT),ALGTH(IUNIT),TMUNIT(IUNIT),TUNIT(
     2IUNIT),HO(JXX),SHO(JXX),ALGTH(IUNIT),TMUNIT(IUNIT),TUNIT(IUNIT),EU
     3NIT(IUNIT),RFI(JXX),SRFI(JXX),ALGTH(IUNIT),TMUNIT(IUNIT),TUNIT(IUN
     4IT),EUNIT(IUNIT),RFO(JXX),SRFO(JXX),EUNIT(IUNIT),ALGTH(IUNIT),TMUN
     5IT(IUNIT),TUNIT(IUNIT),UD(JXX),SUD(JXX)
  340 FORMAT(/////5X,'HEAT EXCHANGER DATA'//44X,'NOMINAL VALUE',13X,'STD
     1'//5X,'INSIDE COEFF.,',A3,'/','SQR ',A2,' ',A2,' DEG ',A1,8X,F10.5
     2,12X,F10.5/5X,'OUTSIDE COEFF.,',A3,'/','SQR ',A2,' ',A2,' DEG ',A1
     3,7X,F10.5,12X,F10.5/5X,'INSIDE FOULING FACTR,SQR ',A2,' ',A2,' DEG
     4',A1,'/',A3,2X,F10.5,12X,F10.5/5X,'OUTSIDE FOULING FACTR,SQR ',A2,
     5' ',A2,' DEG ',A1,'/',A3,F10.5,12X,F10.5/5X,'OVERALL COEFF.,',A
     63,'/','SQR ',A2,' ',A2,' DEG ',A1,7X,F10.5,12X,F10.5)
      WRITE(NPRNT,342)EUNIT(IUNIT),ALGTH(IUNIT),TMUNIT(IUNIT),TUNIT(IUNI
     1T),KW(JXX)
  342 FORMAT(5X,'TUBE WALL THERMAL CONDTY,',A3,'/',A2,' ',A2,' DEG ',A1,
     111X,F10.5)
  345 WRITE(NPRNT,360)ALGTH(IUNIT),ALGTH(IUNIT),AI(JXX),ALGTH(IUNIT),ALGH
     1TH(IUNIT),AO(JXX)
  360 FORMAT(5X,'TUBE INSIDE WALL AREA SQR',A2,'/',A2,11X,F10.5/5X,'TUBE
     1 OUTSIDE WALL AREA SQR',A2,'/',A2,10X,F10.5)
      NTF=NFA(JXX)
      GO TO (351,352,353),NTF
  351 N=1
      M=2
      GO TO 354
  352 N=3
      M=4
      GO TO 354
  353 N=5
      M=6
  354 WRITE(NPRNT,355)(ARRGT(I),I=N,M),NSP(JXX)
  355 FORMAT(///5X,'FLOW ARRANGEMENT',10X,2A4//5X,'NUMBER OF SHELL-PASSE
     1S',I8)
      IF(IUNIT.NE.2) GO TO 357
      WRITE(NPRNT,366)WISO(JXX),WUNIT(IUNIT),TMUNIT(IUNIT),HFG(JXX),EUNI
     1T(IUNIT),WUNIT(IUNIT),Q(JXX),PUNIT(IUNIT),A(JXX),ALGTH(IUNIT)
  366 FORMAT(/5X,'ISOTHERMAL STREAM FLOW RATE',F10.2,' ',A2,'/',A2//5X
     1,'ISOTHERMAL STREAM ENTHALPY',E11.4,' ',A3,'/',A2//5X,'HEAT TRANSF
     2ERED',E11.4,A3          //5X,'AREA REQUIRED',F10.2,' SQR ',A2)
      IF(NETRN.EQ.0) GO TO 380
      Q(JXX)=Q(JXX)*3.6
      UD(JXX)=UD(JXX)*3.6
      HI(JXX)=HI(JXX)*3.6
      HO(JXX)=HO(JXX)*3.6
      SUD(JXX)=SUD(JXX)*3.6
      SHI(JXX)=SHI(JXX)*3.6
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      S  .(JXX)= [illegible](JXX)*3.                                  HX001830
      [illegible]I(JXX)= [illegible]I(JXX)/3.                         HX001840
      [illegible]FI(JXX)=S[illegible]FI(JXX)/3.                       HX001850
      [illegible](JXX)=[illegible](JXX)/3.                            HX001860
      [illegible](JXX)=SHF (JXX)/3.                                   HX001870
      K[illegible](JXX)=K[illegible](JXX)*3.                          HX001880
      GO TO 390                                                       HX001890
 357  WRITE(NPR[illegible]T,365)WISO(JXX),[illegible]UNIT(IUNIT),T[illegible]UNIT(IUNIT),HFG(JXX),EUNIHX001900
     1T(IUNIT),[illegible]UNIT(IUNIT),Q(JXX),EUNIT(IUNIT),THUNIT(IUNIT),A(JXX),ALGHX001910
     2TH(IUNIT)                                                       HX001920
 365  FORMAT(/5X,'ISOTHERMAL STREAM FLOW RATE',F10.2,' ',A2,'/',A2//5X HX001930
     1,'ISOTHERMAL STREAM ENTHALPY',E11.4,' ',A3,'/',A2//5X,'HEAT TRANSFHX001940
     2ERED',E11.4,' ',A3,'/',A2//5X,'AREA REQUIRED',F10.2,' SQR ',A2) HX001950
 390  RETURN                                                          HX001960
      END                                                             HX001970


      SUBROUTINE HEX(JXX)                                             HEX00010
C                                                                     HEX00020
C     SUBROUTINE HEX CALCULATES THE AREA OR TEMPERATURES FOR HEAT     HEX00030
C     EXCHANGER ELEMENT.                                              HEX00040
C                                                                     HEX00050
      DIMENSION XLMTD(100)                                            HEX00060
      REAL KW(100)                                                    HEX00070
      COMMON/KEYS/IEPR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX      HEX00080
      COMMON/ARAV/AREA(100,500),ANL(100),IREA(100),NUD(100),NQ(100),INFNHEX00090
     1A(100),IZERA(100)                                               HEX00100
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH                                 HEX00110
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20)             HEX00120
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),HEX00130
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1HEX00140
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW                HEX00150
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SRHEX00160
     1FO(100),SUD(100)                                                HEX00170
      COMMON/ADAP/CPC(200),CPH(200),SCPC(200),SCPH(200),NFA(200),NSP(200HEX00180
     1)                                                               HEX00190
      NF1=IFD(JXX,1)                                                  HEX00200
      NF2=IFD(JXX,2)                                                  HEX00210
      NP1=IPD(JXX,1)                                                  HEX00220
      NP2=IPD(JXX,2)                                                  HEX00230
      IF(CPC(JXX).NE.0.0)CP(NF1)=CPC(JXX)                             HEX00240
      IF(CPH(JXX).NE.0.0)CP(NF2)=CPH(JXX)                             HEX00250
      IF(ISC.EQ.1.AND.NETRN.EQ.2) CALL RANDV(JXX)                     HEX00260
      T(NP1)=TP1(JXX)                                                 HEX00270
      T(NP2)=TP2(JXX)                                                 HEX00280
      IF(UD(JXX).EQ.0.0) NUD(JXX)=1                                   HEX00290
      IF(Q(JXX).EQ.0.0)NQ(JXX)=1                                      HEX00300
      IF(NUD(JXX).NE.1)GO TO 30                                       HEX00310
      IF(HI(JXX).EQ.0.0.OR.HO(JXX).EQ.0.0) GO TO 525                  HEX00320
      RW=0.0                                                          HEX00330
      IF(KW(JXX).NE.0.0)RW=ALOG(DO(JXX)/DI(JXX))/(2.0*3.1416*KW(JXX)) HEX00340
      UD(JXX)=1.0/(1.0/HO(JXX)+RFI(JXX)*(AO(JXX)/AI(JXX))+(1.0/HI(JXX))*HEX00350
     *AO(JXX)/AI(JXX)+RFO(JXX)+RW*AO(JXX))                            HEX00360
 30   IF(A(JXX).EQ.0.0) IREA(JXX)=1                                   HEX00370
      IF(IREA(JXX).NE.1) GO TO 100                                    HEX00380
C                                                                     HEX00390
C     CALCULATE AREA                                                  HEX00400
C                                                                     HEX00410
      IF(T(NP1).EQ.0.0.AND.T(NP2).EQ.0.0)GO TO 76                     HEX00420
      IF(T(NP1).NE.0.0.AND.T(NP2).NE.0.0) GO TO 40                    HEX00430
      IF(T(NP1).EQ.0.0.AND.T(NP2).NE.0.0) GO TO 35                    HEX00440
      IF(T(NP2).EQ.0.0.AND.T(NP1).NE.0.0) GO TO 38                    HEX00450
 35   IF(NQ(JXX).NE.0)Q(JXX)=W(NF2)*CP(NF2)*(T(NF2)-T(NP2))           HEX00460
      T(NP1)=T(NF1)+Q(JXX)/(W(NF1)*CP(NF1))                           HEX00470
      GO TO 40                                                        HEX00480
 38   IF(NQ(JXX).NE.0)Q(JXX)=W(NF1)*CP(NF1)*(T(NP1)-T(NF1))           HEX00490
      T(NP2)=T(NF2)-Q(JXX)/(W(NF2)*CP(NF2))                           HEX00500
      GO TO 40                                                        HEX00510
 40   IF(NQ(JXX).NE.0)Q(JXX)=W(NF1)*CP(NF1)*(T(NP1)-T(NF1))           HEX00520
      IF(T(NF1).GE.T(NP1).AND.TP1(JXX).NE.0.0) GO TO 25               HEX00530
      IF(T(NF2).LE.T(NP2).AND.TP2(JXX).NE.0.0) GO TO 25               HEX00540
      IF(T(NP2).LE.T(NF1)) GO TO 27                                   HEX00550
      IF(T(NP1).GE.T(NF2)) GO TO 27                                   HEX00560
      IF(NFA(JXX).EQ.1.AND.T(NP2).LE.T(NP1)) GO TO 27                 HEX00570
      GO TO 42                                                        HEX00580
 25   IZERA(JXX)=IZERA(JXX)+1                                         HEX00590
      GO TO 950                                                       HEX00600
 27   INFNA(JXX)=INFNA(JXX)+1                                         HEX00610
      GO TO 950                                                       HEX00620
 42   NTB=NFA(JXX)                                                    HEX00630
      GO TO (61,62,63),NTB                                            HEX00640
 61   FT(JXX)=1.0                                                     HEX00650
      XLMTD(JXX)=((T(NF2)-T(NF1))-(T(NP2)-T(NP1)))/(ALOG((T(NF2)-T(NF1))HEX00660
     1/(T(NP2)-T(NP1))))                                              HEX00670
      GO TO 50                                                        HEX00680
 62   FT(JXX)=1.0                                                     HEX00690
      GO TO 45                                                        HEX00700
 63   P=(T(NF2)-T(NP2))/(T(NP1)-T(NF1))                               HEX00710
      S=(T(NP1)-T(NF1))/(T(NF2)-T(NF1))                               HEX00720
      DEL1=SQRT(P**2+1.0)                                             HEX00730
      DEL2=(1.0-S)/(1.0-P*S)                                          HEX00740
      DEL3=2.0-S*(P+1.0+DEL1)                                         HEX00750
      DEL4=2.0-S*(P+1.0-DEL1)                                         HEX00760
      DEL5=(1.0-S)*(1.0-P*S)                                          HEX00770
      DEL6=DEL4/DEL3                                                  HEX00780
      IF(DEL3.LE.0.0) GO TO 29                                        HEX00790
      IF(NSP(JXX).GE.2) GO TO 47                                      HEX00800
      FT(JXX)=DEL1*ALOG(DEL2)/((P-1.0)*ALOG(DEL4/DEL3))               HEX00810
      GO TO 45                                                        HEX00820
 47   DEL7=(2.0/S-1.0-P+(2.0/S)*SQRT(DEL5)+DEL1)/(2.0/S-1.0-P+(2.0/S)* HEX00830
     1SQRT(DEL5)-DEL1)                                                HEX00840
      IF(DEL7.LE.0.0) GO TO 29                                        HEX00850
      FT(JXX)=(DEL1/(2.0*(P-1.0)))*ALOG(DEL2)/ALOG(DEL7)              HEX00860
 45   DELTA1=T(NF2)-T(NP1)                                            HEX00870
      DELTA2=T(NP2)-T(NF1)                                            HEX00880
      XLMTD(JXX)=(DELTA1-DELTA2)/ALOG(DELTA1/DELTA2)                  HEX00890
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 50   A(JXX)=Q(JXX)/(UD(JXX)*FT(JXX)*ALMTD(JXX))
      IF(NETRN.EQ.1) ANL(JXX)=A(JXX)
      IF(ISC.GE.1.AND.NETRN.EQ.2)AREA(JXX,IPR)=A(JXX)
      GO TO 950
 29   INFNA(JXX)=INFNA(JXX)+1
      GO TO 950
 100  IF(T(NP1).NE.0.0.AND.T(NP2).NE.0.0) GO TO 950
      IF(T(NP1).EQ.0.0.AND.T(NP2).NE.0.0) GO TO 103
      IF(T(NP2).EQ.0.0.AND.T(NP1).NE.0.0) GO TO 104
      GO TO 135
 103  IF(NQ(JXX).NE.0)Q(JXX)=W(NF2)*CP(NF2)*(T(NF2)-T(NP2))
      T(NP1)=T(NF1)+Q(JXX)/(W(NF1)*CP(NF1))
      GO TO 150
 104  IF(NQ(JXX).NE.0)Q(JXX)=W(NF1)*CP(NF1)*(T(NP1)-T(NF1))
      T(NP2)=T(NF2)-Q(JXX)/(W(NF2)*CP(NF2))
      GO TO 150
 150  IF(Q(JXX).EQ.0.0)Q(JXX)=W(NF1)*CP(NF1)*(T(NP1)-T(NF1))
C
C CALCULATE TEMPERATURES
C
 135  C1=W(NF1)*CP(NF1)
      C2=W(NF2)*CP(NF2)
      IF(C1.EQ.0.0.OR.C2.EQ.0.0)GO TO 140
      IF(C1-C2)870,871,872
  870 CMIN=C1
      CMAX=C2
      GO TO 875
  871 CMIN=C1
      CMAX=CMIN
      GO TO 875
  872 CMIN=C2
      CMAX=C1
  875 ANTU=A(JXX)*UD(JXX)/CMIN
      NTB=NFA(JXX)
      GO TO (876,877,878),NTB
  876 EFF=(1.0-EXP(-ANTU*(1.0+CMIN/CMAX)))/(1.0+CMIN/CMAX)
      IF(NSP(JXX).GT.1) GO TO 880
      GO TO 881
  877 EFF=(1.0-EXP(-ANTU*(1.0-CMIN/CMAX)))/(1.0-(CMIN/CMAX)*EXP(-ANTU*(1
     $.0-CMIN/CMAX)))
      IF(NSP(JXX).GT.1) GO TO 880
      GO TO 881
  878 GAMMA=ANTU*SQRT(1.0+(CMIN/CMAX)**2)
      EFF=2.0/(1.0+CMIN/CMAX+SQRT(1.0+(CMIN/CMAX)**2)*(1.0+EXP(-GAMMA))
     $/(1.0-EXP(-GAMMA)))
      IF(NSP(JXX).LE.1) GO TO 881
 880  NSH=NSP(JXX)
      EFF=(((1.0-EFF*CMIN/CMAX)/(1.0-EFF))**NSH-1.0)/(((1.0-EFF*CMIN/CMA
     $X)/(1.0-EFF))**NSH-CMIN/CMAX)
  881 T(NP2)=T(NF2)-(EFF*CMIN*(T(NF2)-T(NF1)))/C2
      T(NP1)=T(NF1)+(EFF*CMIN*(T(NF2)-T(NF1)))/C1
      IF(Q(JXX).EQ.0.0)Q(JXX)=W(NF2)*CP(NF2)*(T(NF2)-T(NP2))
      GO TO 950
  865 IF(T(NP2).NE.0.0) GO TO 950
      Q(JXX)=W(NF1)*CP(NF1)*ABS(T(NP1)-T(NF1))
      T(NP2)=T(NF2)-Q(JXX)/(W(NF2)*CP(NF2))
      GO TO 950
  866 Q(JXX)=W(NF2)*CP(NF2)*ABS(T(NP2)-T(NF2))
      T(NP1)=T(NF1)+Q(JXX)/(W(NF1)*CP(NF1))
  950 W(NP2)=W(NF2)
      W(NP1)=W(NF1)
      CP(NP2)=CP(NF2)
      CP(NP1)=CP(NF1)
      IERR(JXX)=0
      GO TO 910
  900 IERR(JXX)=1
  76  WRITE(NPRNT,80)
  80  FORMAT('1','BOTH OF THE OUTLET TEMPERATURES ARE NOT SPECIFIED')
      GO TO 910
 140  WRITE(NPRNT,141)
 141  FORMAT('1','THE FLOW RATE OR THE HEAT CAPACITY IS ZERO')
      IERR(JXX)=1
      GO TO 910
 625  WRITE(NPRNT,626)
 626  FORMAT('1'/////5X,'HEAT EXCHANGER NUMBER**',I3//5X,'HEAT TRANSFER
     1COEFF. IS ZERO')
      IERR(JXX)=1
  910 RETURN
      END
```

```
      SUBROUTINE HRCR(JXX)
C
C     SUBROUTINE HRCR CALCULATES THE AREA OR OUTLET TEMPERATURE FOR
C     HEATER OR COOLER ELEMENT
C
      DIMENSION XLMTD(100)
      REAL KW(100)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH
      COMMON/ARAV/AREA(100,500),ANL(100),IREA(100),NUD(100),NQ(100),INFN
     1A(100),IZERA(100)
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20)
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SR
     1FO(100),SJD(100)
      COMMON/ADAP/CPC(200),CPH(200),SCPC(200),SCPH(200),NFA(200),NSP(200
     1)
      IF=IFD(JXX,1)
      IP=IPD(JXX,1)
      IF(CPC(JXX).NE.0.0)CP(IF)=CPC(JXX)
      IF(ISC.EQ.1.AND.NETRN.EQ.2) CALL RANDV(JXX)
      IF(Q(JXX).EQ.0.0)Q(JXX)=WISO(JXX)*HFG(JXX)
      IF(Q(JXX).EQ.0.0) NQ(JXX)=1
```

```
      T(IP)=TP1(JXX)
      IF(UD(JXX).EQ.0.0) NUD(JXX)=1
      IF(NUD(JXX).NE.1) GO TO 650
      IF(HI(JXX).EQ.0.0.OR.HO(JXX).EQ.0.0) GO TO 625
      RW=0.0
      IF(KW(JXX).NE.0.0)RW=ALOG(DO(JXX)/DI(JXX))/(2.0*3.1416*KW(JXX))
      UD(JXX)=1.0/(1.0/HO(JXX)+RFI(JXX)*(AO(JXX)/AI(JXX))+(1.0/HI(JXX))*
     $AO(JXX)/AI(JXX)+RFO(JXX)+RW*AO(JXX))
  660 IF(A(JXX).EQ.0.0) IREA(JXX)=1
      IF(IREA(JXX).NE.1.AND.T(IP).EQ.0.0) GO TO 600
C
C     CALCULATE AREA
C
      IF(TISO(JXX).EQ.0.0) GO TO 617
      IF(NQ(JXX).NE.1) GO TO 560
      IF(T(IP).EQ.0.0) GO TO 615
      IF(T(IF).GE.T(IP)) GO TO 550
      IF(T(IP).GE.TISO(JXX)) GO TO 570
      Q(JXX)=W(IF)*CP(IF)*(T(IP)-T(IF))
      IF(Q(JXX).EQ.0.0) GO TO 615
      GO TO 666
  560 IF(TP1(JXX).NE.0.0.AND.W(IF).EQ.0.0)W(IF)=Q(JXX)/(CP(IF)*(T(IP)-T(
     1IF)))
      IF(TP1(JXX).EQ.0.0.AND.W(IF).NE.0.0)T(IP)=T(IF)+Q(JXX)/(W(IF)*CP(I
     1F))
      IF(T(IP).GE.TISO(JXX)) GO TO 570
  666 IF(HFG(JXX).EQ.0.0.AND.WISO(JXX).NE.0.0)HFG(JXX)=ABS(Q(JXX)/WISO(J
     1XX))
      IF(WISO(JXX).EQ.0.0.AND.HFG(JXX).NE.0.0)WISO(JXX)=ABS(Q(JXX)/HFG(J
     1XX))
      DELTA1=TISO(JXX)-T(IP)
      DELTA2=TISO(JXX)-T(IF)
      XLMTD(JXX)=(DELTA1-DELTA2)/ALOG(DELTA1/DELTA2)
      A(JXX)=ABS(Q(JXX)/(UD(JXX)*XLMTD(JXX)))
      IF(NETRN.EQ.1) ANL(JXX)=A(JXX)
      IF(ISC.GE.1.AND.NETRN.EQ.2)AREA(JXX,IPR)=A(JXX)
      GO TO 650
  550 IZERA(JXX)=IZERA(JXX)+1
      GO TO 650
  570 INFNA(JXX)=INFNA(JXX)+1
      GO TO 650
C
C     CALCULATE TEMPERATURES
C
  600 IF(NQ(JXX).NE.1.AND.W(IF).NE.0.0) T(IP)=T(IF)+Q(JXX)/(W(IF)*CP(IF)
     1)
      IF(T(IP).NE.0.0) GO TO 650
      IF(TISO(JXX).EQ.0.0.OR.W(IF).EQ.0.0) GO TO 617
      X=UD(JXX)*A(JXX)/(W(IF)*CP(IF))
      T(IP)=TISO(JXX)-(TISO(JXX)-T(IF))*EXP(-X)
      IF(Q(JXX).EQ.0.0)Q(JXX)=W(IF)*CP(IF)*(T(IP)-T(IF))
      GO TO 650
  615 WRITE(NPRNT,620) JXX
  620 FORMAT('1'/////5X,'HEAT EXCHANGER NUMBER**',I3//5X,'EXCHANGER DUTY
     1 WAS NOT SPECIFIED'/5X,'*******************************************
     2****************************')
      IERR(JXX)=1
      GO TO 700
  616 WRITE(NPRNT,630)JXX
  630 FORMAT('1'/////5X,'HEAT EXCHANGER NUMBER**',I3/////5X,'ONE OF THE
     1TWO STREAMS TEMPERATURES IS ZERO AND CAN NOT BE CALCULATED')
      IERR(JXX)=1
      GO TO 700
  617 WRITE(NPRNT,640)JXX
  640 FORMAT('1'/////5X,'EITHER THE ISOTHERMAL STREAM TEMPERATURE OR THE
     1FLOW RATE OF THE COLD STREAM WAS NOT SPECIFIED'/5X,'***************
     2*******************************************************************
     3*************')
      IERR(JXX)=1
      GO TO 700
  625 WRITE(NPRNT,626)
  626 FORMAT('1'/////5X,'HEAT EXCHANGER NUMBER**',I3//5X,'HEAT TRANSFER
     1COEFF. IS ZERO')
      IERR(JXX)=1
  650 W(IP)=W(IF)
      CP(IP)=CP(IF)
      IERR(JXX)=0
  700 RETURN
      END
```

```
      SUBROUTINE RANDV(JXX)
C
C     SUBROUTINE RANDV GENERATES RANDOM NUMBERS FOR SPECIFIED VARIABLES.
C
      REAL KW(100)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20)
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SR
     1FO(100),SUD(100)
      COMMON/MEAN/HIM(100),HOM(100),RFIM(100),RFOM(100),WM(200),TM(200)
     1,CPM(200),UMD(100)
      COMMON/ADAP/CPC(200),CPH(200),SCPC(200),SCPH(200),NFA(200),NSP(200
     1)
      COMMON//IXX
      IF(NF(JXX).NE.0) GO TO 50
      IF(IPR.GT.1) GO TO 806
      MINPT=NP(JXX)
      DO 5 N=1,MINPT
      IPT=IPD(JXX,N)
      WM(IPT)=W(IPT)
      TM(IPT)=T(IPT)
```

```
      CPM(IPT)=CP(IPT)
    5 CONTINUE
  806 MINPT=NP(JXX)
      DO 10 N=1,MINPT
      IPT=IPD(JXX,N)
      IF(SW(IPT).EQ.0.0) GO TO 20
      SW1=SW(IPT)
      WM1=WM(IPT)
      CALL GAUSS(JX,SW1,WM1,V1)
      W(IPT)=V1
      IF(IXX.NE.0) JX=IXX
   20 IF(ST(IPT).EQ.0.0) GO TO 10
      ST1=ST(IPT)
      TM1=TM(IPT)
      CALL GAUSS(JX,ST1,TM1,V2)
      T(IPT)=V2
      IF(IXX.NE.0) JX=IXX
   10 CONTINUE
      GO TO 905
   50 NF1=IFD(JXX,1)
      NF2=IFD(JXX,2)
      NP1=IPD(JXX,1)
      NP2=IPD(JXX,2)
      IF(IPR.GT.1) GO TO 807
      HIM(JXX)=HI(JXX)
      HOM(JXX)=HO(JXX)
      RFIM(JXX)=RFI(JXX)
      RFOM(JXX)=RFO(JXX)
      UMD(JXX)=UD(JXX)
      CPM(NF1)=CP(NF1)
      CPM(NF2)=CP(NF2)
  807 UDM=UMD(JXX)
      HMI=HIM(JXX)
      HMO=HOM(JXX)
      RFMI=RFIM(JXX)
      RFMO=RFOM(JXX)
      CPM1=CPM(NF1)
      CPM2=CPM(NF2)
      SIH=SHI(JXX)
      SOH=SHO(JXX)
      SIRF=SRFI(JXX)
      SORF=SRFO(JXX)
      UDS=SUD(JXX)
      SCP1=SCP(NF1)
      SCP2=SCP(NF2)
      IF(SCP1.EQ.0.0) GO TO 780
      CALL GAUSS(JX,SCP1,CPM1,V6)
      CP(NF1)=V6
      IF(IXX.NE.0) JX=IXX
  780 IF(SCP2.EQ.0.0) GO TO 790
      CALL GAUSS(JX,SCP2,CPM2,V7)
      CP(NF2)=V7
      IF(IXX.NE.0) JX=IXX
  790 IF(UDS.EQ.0.0) GO TO 808
      CALL GAUSS(JX,UDS,UDM,V9)
      UD(JXX)=V9
      IF(IXX.NE.0) JX=IXX
  808 IF(SIH.EQ.0.0) GO TO 809
      CALL GAUSS(JX,SIH,HMI,V1)
      HI(JXX)=V1
      IF(IXX.NE.0) JX=IXX
  809 IF(SOH.EQ.0.0) GO TO 810
      CALL GAUSS(JX,SOH,HMO,V2)
      HO(JXX)=V2
      IF(IXX.NE.0) JX=IXX
  810 IF(SIRF.EQ.0.0)GO TO 813
      CALL GAUSS(JX,SIRF,RFMI,V3)
      RFI(JXX)=V3
      IF(IXX.NE.0) JX=IXX
  813 IF(SORF.EQ.0.0) GO TO 905
      CALL GAUSS(JX,SORF,RFMO,V4)
      RFO(JXX)=V4
      IF(IXX.NE.0) JX=IXX
      IERR(JXX)=0
  905 RETURN
      END


      SUBROUTINE VAHX(JXX)
C
C     SUBROUTINE VAHX CALCULATES THE MEAN AND STANDARD DEVIATION FOR THE
C     AREA OF EACH HEAT EXCHANGER.
C
      COMMON//ID(18)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX
      COMMON/ARAV/AREA(100,500),ANL(100),IREA(100),NUD(100),NO(100),INF
     1A(100),IZERA(100)
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     $100),LUNIT(100),PUNIT(2)
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH
      DATA NTLE/0/
  375 FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,1X,'*** OUTPUT LIST
     1ING ***')
      IF(NTLE.NE.0) GO TO 410
      WRITE(NPRNT,375)ID
      NTLE=1
  410 SUMA=0.0
      SUMA2=0.0
      LM=0
      DO 420 K=1,LX
      IF(AREA(JXX,K).EQ.0.0) LM=LM+1
  420 SUMA=SUMA+AREA(JXX,K)
      ALX=LX-LM
      LXR=ALX
      ABAR=SUMA/ALX
      IUNIT=LUNIT(JXX)
```

```
      DO 430 K=1,LX
      IF(AREA(JXX,K).EQ.0.0) GO TO 430
      A1=AREA(JXX,K)-ABAR
      A2=A1*A1
      SUMA2=SUMA2+A2
  430 CONTINUE
      STDA=SQRT(SUMA2/(ALX-1.0))
      WRITE(NPRNT,450)JXX,LX,IZERA(JXX),INFNA(JXX),ABAR,ALGTH(IUNIT),
     1STDA,ALGTH(IUNIT)
  450 FORMAT(////5X,'ELEMENT NUMBER**',I3//5X,'TOTAL NUMBER OF SIMULATIO
     1NS**',I3/5X,'NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEE
     2DED**',I3/5X,'NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS
     3 CAN NOT BE MET**',I3/5X,'MEAN AREA FOR THE REMAINING SIMULATIONS*
     4*',F10.3,' SQR ',A2/5X,'STANDARD DEVIATION FOR THE REMAINING SIMUL
     5ATIONS**',F10.3,' SQR ',A2)
      RETURN
      END


      SUBROUTINE PRINT(JXX)
C
C     SUBROUTINE PRINT CALCULATES THE MAXIMUM AND MINIMUM TEMPERATURES
C     FOR EACH OUTLET STREAM
C
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20)
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW(100)
      COMMON/VAMXN/WMAX(20),WMIN(20),TMAX(20),TMIN(20),WOPT(20,500),TOPT
     $(20,500)
      MOPT=NF(JXX)
      DO 115 II=1,MOPT
      IN=IFD(JXX,II)
      TMAX(II)=AMAX1(TMAX(II),T(IN))
      TMIN(II)=AMIN1(TMIN(II),T(IN))
      TOPT(II,IPR)=T(IN)
  115 CONTINUE
      RETURN
      END


      SUBROUTINE OTPT(JXX)
C
C     SUBROUTINE OTPT READS OUTPUT STREAM NUMBERS AND PRINT THEIR
C     CONDITIONS.
C
      DIMENSION R(50),D(50),CY(50),SR(50),SD(50),SCY(50)
      REAL KW(100)
      COMMON//ID(18)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     $100),LUNIT(100),PUNIT(2)
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20)
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SR
     1FO(100),SUD(100)
      DATA R,D,CY,SR,SD,SCY/50*0.0,50*0.0,50*0.0,50*0.0,50*0.0,50*0.0/
  370 FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,2X,'*** INPUT LISTI
     1NG ***')
  375 FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,1X,'*** OUTPUT LIST
     1ING ***')
      IF(NETRN.EQ.0)WRITE(NPRNT,370)ID
      IF(NETRN.EQ.1.AND.NXX.EQ.2)WRITE(NPRNT,375)ID
      MOTPT=NF(JXX)
      IF(NETRN.NE.0) GO TO 20
      READ(NREAD,10)(IFD(JXX,MN),MN=1,20)
   10 FORMAT(14I5/6I5)
   20 DO 50 MM=1,MOTPT
      IPT=IFD(JXX,MM)
      R(MM)=W(IPT)
      D(MM)=T(IPT)
      CY(MM)=CP(IPT)
      SR(MM)=SW(IPT)
      SD(MM)=ST(IPT)
      SCY(MM)=SCP(IPT)
   50 CONTINUE
      WRITE(NPRNT,25)JXX,NF(JXX),NP(JXX)
   25 FORMAT(////1X,'OUTPUT TANK'//1X,'ELEMENT NUMBER**',I3//1X,     'NUM
     1BER OF FEED STREAMS**',I3,' NUMBER OF PRODUCT STREAMS**',I3////
     266X,'FEED')
      K=1
      L=10
   27 WRITE(NPRNT,30)(IFD(JXX,MM),MM=K,L)
   30 FORMAT(//1X,'STREAM NUMBER',14X,I4,9(6X,I4))
      IF(NETRN.EQ.1.AND.NXX.EQ.2)KUNIT(JXX)=LUNIT(JXX)
      IUNIT=KUNIT(JXX)
      WRITE(NPRNT,31)WUNIT(IUNIT),TMUNIT(IUNIT),(R(MM),MM=K,L)
   31 FORMAT(///1X,'FLOW RATE ',A2,'/',A3,8X,10F10.2)
      WRITE(NPRNT,32)TUNIT(IUNIT),(D(MM),MM=K,L)
   32 FORMAT(1X,'TEMPERATURE DEG ',A1,7X,10F10.2)
      WRITE(NPRNT,33)EUNIT(IUNIT),WUNIT(IUNIT),TUNIT(IUNIT),(CY(MM),MM=K
     1,L)
   33 FORMAT(1X,'HEAT CAPACITY ',A3,'/',A2,' ',A1,3X,10F10.5)
      WRITE(NPRNT,34)WUNIT(IUNIT),TMUNIT(IUNIT),(SR(MM),MM=K,L)
   34 FORMAT(1X,'FLOW RATE STD ',A2,'/',A3,4X,10F10.2)
      WRITE(NPRNT,35)TUNIT(IUNIT),(SD(MM),MM=K,L)
   35 FORMAT(1X,'TEMPERATURE STD DEG ',A1,4X,10F10.2)
      WRITE(NPRNT,36)EUNIT(IUNIT),WUNIT(IUNIT),TUNIT(IUNIT),(SCY(MM),MM=
     1K,L)
   36 FORMAT(1X,'HEAT CPY STD ',A3,'/',A2,' ',A1,3X,10F10.5)
```

```
      IF(L.GT.1) GO TO 4
      IF(OTPT.LT.1.0) GO TO ...
      K=11
      L=NOTPT
      WRITE(NPRNT,38)
   38 FORMAT(///////)
      GO TO 27
   40 RETURN
      END
```

```
      SUBROUTINE GRAPH
C
C     SUBROUTINE GRAPH PLOTS THE CUMULATIVE PROBABILITY FOR EACH OUTLET
C     TEMPERATURE.
C
      DIMENSION IZAR(100),X(20)
      COMMON/GUNIT/IUNIGH,NCASE,NYORD
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     $100),LUNIT(100),PUNIT(2)
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH
      COMMON/TCPP/XAR(100),YAR(100),LIMIT,TMINN,IY,TINC
      COMMON/ZAR/IA,TBAR,STDV,RVAR(9)
      DATA IB,IG/' ','*'/
   23 FORMAT(4X,'CUMULATIVE',6X,'*',100A1)
   24 FORMAT(4X,'PROBABILITY',5X,'*',100A1)
      N=LIMIT
      AJJ=TMINN
      WRITE(NPRNT,10)
   10 FORMAT('1'/)
      I=NYORD
      IF(NYORD.EQ.0)I=50
      PINC=1.0/I
      M=I
    5 DO 2 K=1,100
    2 IZAR(K)=IB
      DO 3 J=1,N
      IV=YAR(J)/PINC+.5
      IF(IV.NE.I) GO TO 3
      IX=(XAR(J)-AJJ)/TINC+0.5
      IZAR(IX)=IG
    3 CONTINUE
      IF(I.EQ.(M/2+10)) GO TO 35
      IF((I/10)*10.EQ.I) GO TO 4
      IF(I.NE.(M/2+11)) GO TO 19
      WRITE(NPRNT,25)(IZAR(L),L=1,70),IA
   25 FORMAT(20X,'*',70A1,'EFFLUENT STREAM NO',I6)
      GO TO 6
   35 YP=PINC*I
      WRITE(NPRNT,36)YP,(IZAR(L),L=1,70),TBAR
   36 FORMAT(10X,F8.4,2X,'+',70A1,'STREAM TEMP. MEAN ',F10.3)
      GO TO 6
   19 IF(I.NE.(M/2+10)) GO TO 26
      WRITE(NPRNT,27)(IZAR(L),L=1,70),TBAR
   27 FORMAT(20X,'*',70A1,'STREAM TEMP. MEAN ',F10.3)
      GO TO 6
   26 IF(I.NE.(M/2+9)) GO TO 32
      WRITE(NPRNT,33)(IZAR(L),L=1,70),STDV
   33 FORMAT(20X,'*',70A1,'STANDARD DEVIATION',F10.3)
      GO TO 6
   32 IF(I.NE.(M/2+1)) GO TO 28
      WRITE(NPRNT,23)IZAR
      GO TO 6
   28 IF(I.NE.M/2) GO TO 29
      WRITE(NPRNT,24)IZAR
      GO TO 6
   29 WRITE(NPRNT,20)IZAR
   20 FORMAT(20X,'*',100A1)
      GO TO 6
    4 IF(I.NE.M/2) GO TO 8
      YP=PINC*I
      WRITE(NPRNT,30)YP,IZAR
   30 FORMAT(4X,'PROB.',1X,F8.4,2X,'+',100A1)
      GO TO 6
    8 YP=PINC*I
      WRITE(NPRNT,21)YP,IZAR
   21 FORMAT(10X,F8.4,2X,'+',100A1)
    6 I=I-1
      IF(I.GT.0) GO TO 5
      YP=0.
      WRITE(NPRNT,22)YP
   22 FORMAT(10X,F8.4,2X,'+',10('*********+'))
      DO 9 I=1,11
    9 X(I)=AJJ+(I-1)*10.0*TINC
      WRITE(6,12)(X(I),I=1,11)
   12 FORMAT(13X,11F10.1)
      WRITE(NPRNT,14)TUNIT(IUNIGH)
   14 FORMAT(/45X,'TEMPERATURE DEG ',A1)
      RETURN
      END
```

```
      SUBROUTINE UNITS(JXX)
C
C     SUBROUTINE UNITS CONVERTS UNITS FROM USA SYSTEM TO SI SYSTEM AND
C     VISE VERSA.
C
      REAL KW(100)
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     $100),LUNIT(100),PUNIT(2)
      COMMON/ADAP/CPC(200),CPH(200),SCPC(200),SCPH(200),NFA(200),NSP(200
     1)
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),
```

```
     1RFI(100),RFO(100),HI(100),HO(100),TISO(100),FT(100),TP1(100),TP2(1UNIT0120
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW                 UNIT0130
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),S-UNIT0140
     1FO(100),SUD(100)                                                 UNIT0150
      COMMON/KEYS/IERP(100),NELM(100),NXX,NETPN,NX,IPR,ISC,LX,JX        UNIT0160
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20)               UNIT0170
      IF(LUNIT(JXX).EQ.KUNIT(JXX)) GO TO 55                             UNIT0180
      IF(LUNIT(JXX).EQ.1.AND.KUNIT(JXX).EQ.2) GO TO 40                  UNIT0190
C                                                                       UNIT0200
C     CONVERT TO SI UNITS                                               UNIT0210
C                                                                       UNIT0220
      IF(NF(JXX).NE.0.AND.NP(JXX).NE.0) GO TO 30                        UNIT0230
      MINPT=NP(JXX)                                                     UNIT0240
      DO 20 M=1,MINPT                                                   UNIT0250
      NSTM=IPD(JXX,M)                                                   UNIT0260
      W(NSTM)=W(NSTM)/2.205                                             UNIT0270
      T(NSTM)=(1.0/1.8)*(T(NSTM)-32.0)+273.16                           UNIT0280
      CP(NSTM)=CP(NSTM)*4.1868                                          UNIT0290
      SW(NSTM)=SW(NSTM)/2.205                                           UNIT0300
      ST(NSTM)=0.5556*ST(NSTM)                                          UNIT0310
      SCP(NSTM)=SCP(NSTM)*4.1868                                        UNIT0320
   20 CONTINUE                                                          UNIT0330
      GO TO 55                                                          UNIT0340
   30 Q(JXX)=Q(JXX)*1.055                                               UNIT0350
      A(JXX)=A(JXX)/(3.281)**2                                          UNIT0360
      UD(JXX)=UD(JXX)*20.4418                                           UNIT0370
      HI(JXX)=HI(JXX)*20.4418                                           UNIT0380
      HO(JXX)=HO(JXX)*20.4418                                           UNIT0390
      RFI(JXX)=RFI(JXX)/20.4418                                         UNIT0400
      RFO(JXX)=RFO(JXX)/20.4418                                         UNIT0410
      KW(JXX)=KW(JXX)*6.2306                                            UNIT0420
      AI(JXX)=AI(JXX)/3.281                                             UNIT0430
      AO(JXX)=AO(JXX)/3.281                                             UNIT0440
      TISO(JXX)=(1.0/1.8)*(TISO(JXX)-32.0)+273.16                       UNIT0450
      WISO(JXX)=WISO(JXX)/2.205                                         UNIT0460
      HFG(JXX)=HFG(JXX)*2.326                                           UNIT0470
      IF(TP1(JXX).EQ.0.0) GO TO 35                                      UNIT0480
      TP1(JXX)=(1.0/1.8)*(TP1(JXX)-32.0)+273.16                         UNIT0490
   35 IF(TP2(JXX).EQ.0.0) GO TO 36                                      UNIT0500
      TP2(JXX)=(1.0/1.8)*(TP2(JXX)-32.0)+273.16                         UNIT0510
   36 CPC(JXX)=CPC(JXX)*4.1868                                          UNIT0520
      CPH(JXX)=CPH(JXX)*4.1868                                          UNIT0530
      SUD(JXX)=SUD(JXX)*20.4418                                         UNIT0540
      SHI(JXX)=SHI(JXX)*20.4418                                         UNIT0550
      SHO(JXX)=SHO(JXX)*20.4418                                         UNIT0560
      SRFI(JXX)=SRFI(JXX)/20.4418                                       UNIT0570
      SRFO(JXX)=SRFO(JXX)/20.4418                                       UNIT0580
      SCPC(JXX)=SCPC(JXX)*4.1868                                        UNIT0590
      SCPH(JXX)=SCPH(JXX)*4.1868                                        UNIT0600
      GO TO 55                                                          UNIT0610
C                                                                       UNIT0620
C     CONVERT TO USA UNITS                                              UNIT0630
C                                                                       UNIT0640
   40 IF(NF(JXX).NE.0.AND.NP(JXX).NE.0) GO TO 45                        UNIT0650
      MINPT=NP(JXX)                                                     UNIT0660
      DO 42 M=1,MINPT                                                   UNIT0670
      NSTM=IPD(JXX,M)                                                   UNIT0680
      W(NSTM)=W(NSTM)*2.205                                             UNIT0690
      T(NSTM)=(T(NSTM)-273.16)*1.8+32.0                                 UNIT0700
      CP(NSTM)=CP(NSTM)*0.23885                                         UNIT0710
      SW(NSTM)=SW(NSTM)*2.205                                           UNIT0720
      ST(NSTM)=1.8*ST(NSTM)                                             UNIT0730
      SCP(NSTM)=SCP(NSTM)*0.23885                                       UNIT0740
   42 CONTINUE                                                          UNIT0750
      GO TO 55                                                          UNIT0760
   45 Q(JXX)=Q(JXX)*3.412                                               UNIT0770
      A(JXX)=A(JXX)*(3.281)**2                                          UNIT0780
      UD(JXX)=UD(JXX)/5.6783                                            UNIT0790
      HI(JXX)=HI(JXX)/5.6783                                            UNIT0800
      HO(JXX)=HO(JXX)/5.6783                                            UNIT0810
      RFI(JXX)=RFI(JXX)*5.6783                                          UNIT0820
      RFO(JXX)=RFO(JXX)*5.6783                                          UNIT0830
      AI(JXX)=AI(JXX)*3.281                                             UNIT0840
      AO(JXX)=AO(JXX)*3.281                                             UNIT0850
      TISO(JXX)=(TISO(JXX)-273.16)*1.8+32.0                             UNIT0860
      WISO(JXX)=WISO(JXX)*2.205                                         UNIT0870
      HFG(JXX)=HFG(JXX)/2.326                                           UNIT0880
      TP1(JXX)=(TP1(JXX)-273.16)*1.8+32.0                               UNIT0890
      TP2(JXX)=(TP2(JXX)-273.16)*1.8+32.0                               UNIT0900
      CPC(JXX)=CPC(JXX)*0.23885                                         UNIT0910
      CPH(JXX)=CPH(JXX)*0.23885                                         UNIT0920
      SUD(JXX)=SUD(JXX)/5.6783                                          UNIT0930
      SHI(JXX)=SHI(JXX)/5.6783                                          UNIT0940
      SHO(JXX)=SHO(JXX)/5.6783                                          UNIT0950
      SRFI(JXX)=SRFI(JXX)*5.6783                                        UNIT0960
      SRFO(JXX)=SRFO(JXX)*5.6783                                        UNIT0970
      SCPC(JXX)=SCPC(JXX)*0.23885                                       UNIT0980
      SCPH(JXX)=SCPH(JXX)*0.23885                                       UNIT0990
      GO TO 55                                                          UNIT1000
   55 RETURN                                                            UNIT1010
      END                                                               UNIT1020
```

```
      SUBROUTINE GAUSS(IX,S,AM,V)                                       GAUS0010
C                                                                       GAUS0020
C     GENERATE NORMAL RANDOM NUMBERS                                    GAUS0030
C                                                                       GAUS0040
      COMMON//IXX                                                       GAUS0050
      A=0.0                                                             GAUS0060
      DO 50 I=1,12                                                      GAUS0070
      CALL RANDU(IX,IY,Y)                                               GAUS0080
      IX=IY                                                             GAUS0090
   50 A=A+Y                                                             GAUS0100
      V=(A-6.0)*S+AM                                                    GAUS0110
      IXX=IX                                                            GAUS0120
      RETURN                                                            GAUS0130
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      END                                                      [illegible]

      SUBROUTINE RANDU(IX,IY,YFL)                              RNDU0010
C                                                              RNDU0020
C     GENERATE UNIFORM RANDOM NUMBERS                          RNDU0030
C                                                              RNDU0040
      IY=IX*65539                                              RNDU0050
      IF(IY)5,6,6                                              RNDU0060
    5 IY=IY+2147483647+1                                       RNDU0070
    6 YFL=IY                                                   RNDU0080
      YFL=YFL*.4656613E-9                                      RNDU0090
      RETURN                                                   RNDU0100
      END                                                      RNDU0110

$ENDLIST
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VITA

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Doctor of Philosophy

Thesis: ESTIMATION OF THE PERFORMANCE OF SHELL AND TUBE HEAT EXCHANGER SYSTEMS WHEN UNCERTAINTIES EXIST

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